Fiber Web Rewetting Modeling via Lattice-Boltzmann Method

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LETTER OF TRANSMITTAL

Paper Machine Energy Savings: Reduced Rewetting Via Lattice-Boltzmann Method Approach
Western Michigan University, Fall 2021
Department of Chemical and Paper Engineering

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April 12, 2021

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Dr. Springstead and Dr. Qi,

We have submitted this proposal, upon inquiry, regarding the application of reduced rewetting using the Lattice-Boltzmann Method in order to save energy on paper machine operations. We have deemed this proposal to be valuable and constructed the following report for review. Upon review, it should be found that the report states the inquiry, work performed to obtain through simulations and calculations, financial and economic predictions, recommended next steps, and a conclusion regarding paper machine energy savings through reduced rewetting.

Modern day paper mills are constantly striving to increase profitability margins through sustainable tactics and without losing quality in the paper products being produced. So, in order to decrease energy costs of a modern-day paper machine, it is recommended that the standard roll press be replaced by an extended press-nip. This substitution of equipment has displayed the ability to produce paper with a lower water content after the press section, which requires less energy to dry in the steam-drive dryer section of the paper machine. This proposal doesn’t affect the quality of the paper in any negative way.

To ensure that this proposal is economically feasible, an economic analysis was performed. This analysis found that the net present value of the investment of an extended nip-press was around $1.86 million. The return on investment for this project was calculated to be around 250%, with an IRR of 14%. The payback period of this investment was calculated to be just short of 5 years. Finally, this analysis was performed with a minimal accepted rate of return (MARR) of 20%. Due to the net present value being shown as positive, along with the other found economic values, the investment for this proposal is being recommended.
This report is submitted with full adherence to all provided guidelines and has omitted no applicable information. For further details please contact any of the following project members.

Respectfully,

Omar Kamal

Ian Geiger

Landon Haight

Andrew McCabe

Zac Weber
Utilization of computer modeling software to simulate flexible woody fibers settling onto a filtering mesh akin to many paper machines forming sections. A Lattice-Boltzmann Method, in which a lattice is formed to mimic fluid behaviors via modeled streaming and collision processes, is utilized to model the flow of water near and around these fibers. This process can be used to analyze various subjects such as web rewetting, the effects of jet-to-wire speed variation, effects of various fiber length distributions, and many more situations. Specifically, fiber rewetting will be modeled after burst versus extended pressures to model the wet-press section of a paper machine.

With the implementation of an extended-nip press as an overall process modification, which would replace the conventional roll press, it is estimated that there is an approximate 4% energy saving’s derived from reduced rewetting at the press of 1%. Using industry averages and defined values, representing increasing press solids, an average savings of $3944.10 was observed based on the reduction of natural gas costs needed to satisfy the processes' outstanding energy requirements.
PAPER MACHINE ENERGY SAVINGS: REDUCED REWETTING VIA LATTICE-BOLTZMANN METHOD APPROACH

by

Omar Kamal Aly
Ian Geiger
Landon Haight
Andrew McCabe
Zac Weber

An undergraduate thesis submitted to the
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In partial fulfillment of the requirements
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Paper and or Chemical Engineering
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Thesis Committee:

Dewei Qi, Ph.D., Advisor
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EXECUTIVE SUMMARY

This project involves the design and economic feasibility of substituting an extended nip-press for a roll press in a paper machine to reduce rewetting and result in energy savings. This implementation of an extended nip-press is proposed for a modern-day paper machine for a generic paper mill that is powered using natural gas. Paper machines require large amounts of energy to operate, in order to stay profitable paper companies are always searching for innovative ways to decrease energy costs. Most of the energy usage in a paper machine occurs in the drying portion of the process, so it is being suggested in replacing the generic roll press in a paper machine with an extended nip-press. Simulations show that this will result in a decrease in water content in the paper at the end of the wet press section. Calculations prove that with a lower content of water, less energy is needed to dry the paper.

For this project to be successful, it must be known that there is a market available for paper. A market survey shows that there is currently no significant sign of decrease in demand regarding paper. Also, the market survey showed that the price of natural gas over the past 15 years is not trending upward, which is a positive sign in regard to being able to keep paper plant costs low.

A very important aspect of the project is the profitability of the proposal. This can be interpreted through economic values such as net present value, payback period, return on investment, and internal rate of return. The net present value (NPV) of the proposed investment was found to be around $1.86 million. The payback period (PBP) was calculated to occur just short of 5 years. The return on investment (ROI) was found to be 250%. Finally, the internal rate of return (IRR) was found to be 14%. These economic allow for the recommendation of implementation of this proposal.
INTRODUCTION AND PROBLEM STATEMENT

Heat consumption in the paper industry is a large driver of overall process cost and makes up the majority of non-stock costs [1]. Ever-increasing attempts have been made to improve the solids content into and through the press section of the paper machine such that the thermal demand could be curbed. This would result in the ability to produce higher tonnage of paper per day or to reduce energy requirements for the same end quantity of paper product.

BACKGROUND

Pressing

After the initial sheet formation has occurred in the forming section, the wet web lattice structure has been laid into place. The goal of the pressing section is to remove as much water as possible without unnecessarily crushing the web causing paper breaks or creating localized areas of improper fine and filler removal or fiber realignment. The wet press serves the crucial role in sheet consolidation as well as removing water mechanically from the web. This consolidation aids in improving the bonded strength between fibers by conforming their bonded areas closer together (Figure 1). It is this mechanical dewatering that is highly cost-positive in comparison to the steam drying found in dryer sections (see ‘Calculation of 1% Reduction of Water at Press’ for verification of general industry knowledge on this subject).
Conventional roll presses utilized in the paper making process utilize a crown roll that can internally apply varied hydraulic pressure to lubricated ways such as to bend in a convex nature to correct for the bending of the roll across its length. These rolls apply pressure in short high peaks (Figure 3).

Whereas, as of the early 1980s there has been developed a press system that elongates the press nip from 1-2 inches of contact to now in excess of 10 inches of contact. These extended nip presses, or shoe presses, now utilize a top crown roll similar to a conventional roll press but the
bottom roll has been replaced with a metal wear shoe in the shape of the top roll as well as a rubber blanket, or belt, which serves as the lubrication system for the shoes wear surface (Figure 3). The total peak pressure has to be reduced but the length of time now inside the nip can increase 7 to 8 times (Figure 2). It is in this varied style of pressure application that better dewatering can be found. Dewatering is aided by there being more time for applied vacuum to remove present water [1].

![Figure 3 - Shoe press with extended nip](image)

**Young’s Modulus**

The Young’s Modulus of elasticity, E, is found on stress-strain curves as the slope of the curve prior to the yield point (Figure 4). Beyond this point on the curve, plastic deformation can no longer occur.
In paper-making, the Young’s modulus of elasticity of less refined sheets will be lower than the value calculated for the more refined sheet. This difference would lead some to believe that the change in modulus of elasticity illustrates that the less refined fibers are stiffer and less able to exhibit plastic deformation than the less stiff, more refined fibers.

Tensile Energy Absorption (TEA)

When discussing the tensile energy absorption, TEA, it is important to characterize what this means for the related stress-strain curve. It is visible below that the load-elongation curve ends when the specimen fails (Figure 5). This point of breakage would be considered the tensile strength, kN/m, of the paper as well as the breaking strain, %. The TEA is the area under the stress-strain curve and is the work necessary to break the specimen. When comparing the average TEA value of the 3000-revolutions paper and the 500-revolutions paper below, stress increases from approximately 100 Nm g⁻¹ to 120 Nm g⁻¹. Thus, with an endpoint change, there occurs an increase in TEA.
RESEARCH REVIEW

An overview of the Lattice Boltzmann method

Back in the 1960s, a simpler model of fluid mechanics equations. Reviewing the Boltzmann Kinetic equation, the lattice Boltzmann method uses the lattice Boltzmann equation is a simplified form of the Boltzmann Kinetic equation. The LBE simulates the dynamic behavior of flow without having to solve fluid mechanics equations. This occurs through the minimizing of the degrees of freedom related to velocity. LBE minimizes the degrees of freedom by assuming that at each position, the particle is only allowed to move in a finite number of directions.

What makes LBE in solving fluid problems unique is their space-time locality. Instead of studying lines that are space and time dependent, and also defined by flow speed. The constant velocities related to the lattice in LBE are studied.

The above concept is used to generate the equations of fluid mechanics but limited to the long wavelengths. However, LBE are formulated to serve as an alternative for Navier-Stokes equations.
### Mathematical formulation

1) $\vec{v} \cdot \nabla f = C(f, f)$
   - **LHS**: the free streaming of the particles.
   - **RHS**: the changes in the *probability distribution function* $f(\vec{r}, \vec{v}; t)$ induced by inter-particle collisions.

2) $f_i(\vec{r} + \vec{c}_i \Delta t, t + \Delta t) = f_i(\vec{r}, t) + \Omega_{ij}(f^{eq}_i(\vec{r}, t) - f_j(\vec{r}, t))$
   - $f_i(\vec{r}, t)$: probability of locating a particle at position $\vec{r}$ and time $t$ with velocity $\vec{v}^* = \vec{c}_i$
   - $f^{eq}_i(\vec{r}, t) = w_i \rho (1 + (u_{a\text{ia}} / c_s^2) + (u_{a\text{ub}} Q_{ab} / 2 c_s^4)) @ density \rho = \sum f_i$ and velocity $u^* = \sum f_i \vec{c}_i / \rho$.
   - $w_i$: set of weights (simplified to unity).
   - $Q_{ab} = -c_s^2 \delta_{ab}$ is the quadrupole projector along direction $i$.
   - $c_s^2 = \sum_i w_i c_i$ is the sound speed of the lattice.

---

**Figure 6 - Lattice-Boltzmann Method Graphical Approach**

- Lattice grid representation with particle distribution and direction vectors.
- Probability distribution function $f(\vec{r}, \vec{v}; t)$ shown with bars indicating distribution at different points.
- Velocity vectors $\vec{c}_i$ for different directions.
• a,b are cartesian components.

3) \( e^{-(v-u)^2/2v^2T} = \sum_{n=0} e^{-v^2/2v^2T} (uv/T)^n H_n(v/v_T) \)

• \( vT = (kT/m)^{0.5} \) is thermal speed.

• \( H_n \): Order n tensorial Hermite polynomial.

As shown equation (2) above regenerates the Navier-Stokes equation for quasi-incompressible flows, with ideal equation of state:

4) \( P(\rho) = \rho c^2 s, \)

with kinematic viscosity

5) \( v = c^2 s(\tau - \Delta t/2) \)

• \( \tau \) is the leading non-zero value of the matrix \( \Omega_{ij} \).

The above mathematical formulation had very remarkable schemes and concepts that are essential for LBE computations:

a) In LBE we have non-locality and non-linearity. In the Navier-Stokes equations, this is not the case.

b) Streaming is exact meaning that it is studied along a constant streamline.

c) Boundary conditions are available in terms of basic mechanical rules based on the collisions of molecules with solid walls.

d) Fluid pressure and the strain tensor are linear and highlighted in the equilibrium and non-equilibrium component combinations of the discrete distribution function.

Boundary Conditions

Assumes the net current on the site of collision is zero where we are always reflecting populations at this given site. This gives us a velocity at solid wall equal to zero:
6) \( \mathbf{n} \cdot (\mathbf{r} \times \mathbf{W}) = 0 \)

- \( \mathbf{r} \times \mathbf{W} \) is a glocation on the solid wall.

7) \( \text{fin}(\mathbf{r} \times \mathbf{W}) = \text{fout}(\mathbf{r} \times \mathbf{W}) \)

- in & out: the set of incoming and outgoing populations at the wall.

REWETTING

While applying high pressure over time on the web in a process known as pressing the water is removed from the web. Sometimes water would return to the web which is known as rewetting. This happens as wet paper interfaces are usually water filled and come to contact with wet paper partially. At the nip, the wet paper expands and the vacuum generated will then be filled by air. This air generates a pressure difference and hence allows the interface water to come in stronger contact with paper that eventually increases its moisture content. The phenomenon most appears in the water break of paper and felt. Water on surface have higher attraction to wet paper when compared to felt. Sweet plot below provides a graphical representation for the moisture content.

![Image of rewetting graph]
SIMULATIONS

In conducting the Lattice-Boltzmann Method simulations the below figures were made to aid in the visualization of the tested papermaking phenomena. The model utilized processed fiber webs created to emulate the forming section of the paper machine. Here fibers of a certain quantity per unit meter, varied, are projected out of the slice lip at an initially anisotropic mixture. It is this output mat which was utilized as input for the press section simulations. The press section then applied pressure similar to a form of extended nip press and subsequently a roll press.

Figure 7: Computer Press Simulation, 3D
Figures 7 and 8 provide a visual example of the pressing simulation performed using Linux. The yellow spheres represent the upper and bottom press felts in the paper machine. The orange spheres represent the fibers that are input into the paper machine. Finally, the vectors represent the directions in which water is flowing in the system.
Figures 9 and 10 provide visual representations of the rewetting and pressing portions that occur in the pressing simulations. Figure 9 shows the vectors pointed inward towards the system between the upper and bottom press, this is rewetting. While figure 10 shows the
majority of vectors directed out of the system, which is the dewatering operation that occurs in
the simulation.

Figure 11: Pressure Pulse vs Time

Figure 11 shows the pressure of the system at the specific time of the simulation. The
pressing process that was observed in Figure 10 can be seen to be occurring twice, the first at about
.0018 seconds at a pressure of 4 MPa, and the second pressing occurs at about .0023 seconds at
6.6 MPa. The first pressing is the shoe press, and the second pressing occurs because of the
conventional roll press.
Figures 12 shows the paper thickness at specific times of the simulations using a Young’s Modulus of .1. Figure 13 shows the paper thickness at specific times of the simulations using a Young’s Modulus of .01. Both figures show extremely similar relationships between paper thickness and time. The lowest fiber numbers (F80) in both simulations show the least amount of
paper thickness, while the highest fiber number (F430) show the most paper thickness. So as the Fiber count increases, the paper thickness increases as well. One discrepancy currently presented s for the F80 sample in which with E=0.01 the fibers are found to consolidate well beyond reasonable.

Figure 14: Solid Concentration vs Time, Young's Modulus .1
Figure 14 shows the solid concentration percentage according to the time of the simulation for Young’s Modulus .1. Figure 15 shows the solid concentration percentage according to the time of the simulation for Young’s Modulus .01. These figures show that the solid concentration is highest for the higher solid fiber numbers. This is probably due to the fact that the fiber can be pressed to a greater extent without ruining the physical structure of the sheet.
Figure 16: Moisture Ratio vs Time, Young's Modulus .1

Figure 17: Moisture Ratio vs Time, Young's Modulus .01

Figure 16 shows the moisture ratio according to the time of the simulation for Young’s Modulus .1. Figure 17 shows the moisture ratio according to the time of the simulation for Young’s Modulus .01. For the lower fiber numbers (F160 and F80) in the simulations, it is seen that they are easier to soak during rewetting and easier to dewater during pressing.
Figure 18: Felt-Thickness vs Time, Young's Modulus .1

Figure 19: Felt-Thickness vs Time, Young's Modulus .01

Figure 18 shows the felt thickness according to the time of the simulation for Young’s Modulus .1. Figure 19 shows the felt thickness according to the time of the simulation for Young’s Modulus .01.
Figure 20 shows the distance between the two presses according to the time of the simulation for Young’s Modulus .1. Figure 21 shows the distance between the two presses according to the time of the simulation for Young’s Modulus .01. The distance between the press plates shrinks when pressing is occurring as the fiber mat is consolidated. Also, the lower the number of fiber present, the less distance that is required between the press plates corresponding to a lower basis weight.
Results found above are considered with the known peak pressures. The peak pressures applied were at roughly .0018 seconds and a pressure of 4 MPa for the shoe press; whereas, for the second press, the conventional roll press, occurs at about .0023 seconds at 6.6 MPa. Next, as the fiber quantity increases the paper thickness increases, following conventional logic. Also, as the fiber quantity increases in the simulations the harder it was to remove large amounts of water. The higher the quantity the higher the solid concentration percentage was during the pressing portions of the simulations. it is the opposite in regard to the moisture ratio, when the quantity of fibers is increased the moisture ratio at the presses are lowest. Finally, as quantity of fibers is increased the distance between the two press plates is increased as well.

PROPOSED SCHEMATIC AND PROCEDURES

Industry standard for new paper machines being built almost always includes some form of extended nip press [1]. The reduced water content due to the increased time of pressure addition is general industry knowledge. See Figure 22 below for a reference paper machine layout utilized in modeling.

Figure 22 - Paper machine schematic
Calculation of 1% Reduction of Water at Press

General industry knowledge presumes a 4% savings in total energy use of a paper machine when concentration of solids after the press is increased by 1% [1]. This industry knowledge will be examined more thoroughly here as a prerequisite to the economics contained hereafter.

Assumptions of this process assumes a paper machine running a wet-end temperature of 55°C (135°F) which is derived from low-pressure steam fed through spargers in the pulping process and as such is relatively negligible on these calculations. Motive steam was assumed to be saturated and pressure to be 2 to 5.5 bar (30 – 80 psia), which measures between 120°C and 155°C (240°F and 310°F).

To assess the validity of this claim calculations will be made with the assumptions provided with 49% solids and 50% solids. As the paper grade would be held constant for a fair comparison, the grammage is constant here and therefore the basis of paper fiber is constant between the two sample calculations. Therefore, a basis of .5 kg of paper web after the press section was taken. As both tests require the same amount of fiber, the energy to raise the fiber up to temperature is not calculated as it is constant. Equation 1 below illustrates how the weight of water was determined from desired moisture ($x_{fraction\ of\ water}$) and solids fraction ($x_{mass\ of\ solids}$). These are 51% and .5 kg, respectively.

$$\frac{x_{mass\ of\ water}}{(x_{basis\ of\ solids} + x_{mass\ of\ water})} = x_{fraction\ of\ water}$$

Therefore, the $x_{mass\ of\ water} = 0.52041$ kg water.

In performing the following sensible heat calculations, the heat capacity of water ($C_p$) is assumed to be 4.18 kJ kg$^{-1}$ C$^{-1}$.
Next the latent heat can be calculated. Here the heat of vaporization for water at 100°C in 1 bar of pressure is assumed to be 2095.8 kJ kg\(^{-1}\).

Subsequently, the comparison of heat required:

<table>
<thead>
<tr>
<th></th>
<th>Sensible Heat from Water (49% Solids)</th>
<th>Sensible Heat from Water (50% Solids)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of water (kg)</td>
<td>0.52</td>
<td>0.50</td>
</tr>
<tr>
<td>Heat capacity of water (kJ/kg°C)</td>
<td>4.18</td>
<td>4.18</td>
</tr>
<tr>
<td>Temperature initial (C)</td>
<td>55.00</td>
<td>55.00</td>
</tr>
<tr>
<td>Temperature final (C)</td>
<td>100.00</td>
<td>100.00</td>
</tr>
<tr>
<td>Heat Required (kJ)</td>
<td>97.89</td>
<td>94.05</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Latent Heat from Water (49% Solids)</th>
<th>Latent Heat from Water (50% Solids)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of water (kg)</td>
<td>0.52</td>
<td>0.50</td>
</tr>
<tr>
<td>Heat of Vaporization of Water (kJ/kg)</td>
<td>2095.90</td>
<td>2095.90</td>
</tr>
<tr>
<td>Heat Required (kJ)</td>
<td>1090.73</td>
<td>1047.95</td>
</tr>
</tbody>
</table>

As a rough estimate of general industry knowledge, the above calculations verify that nearly 4% of steam consumed across the dryer cans in the paper-making process is reduced for a 1% improvement in solids gain within the press section.

This information is highly applicable when considering the nature of sheet rewetting. As more water is rewet into the sheet, more water must be evaporated to maintain the same final sheet dryness.
SAFETY AND ENVIRONMENTAL CONSTRAINTS

All safety procedures set forth local, state or federal agencies will be followed in regards to plant safety. This safety can be delineated into areas pertaining to the Environmental Protection Agencies (EPA) rulings and the Occupational Safety and Health Administration (OSHA) – these will apply ‘outside’ and ‘inside the fence’, respectively.

EPA Applicable Standards

For this project, it should be noted that all EPA safety guidelines will be followed to ensure environmental safety. These EPA guidelines prevent the release of toxic materials into the air by conducting inspections of all air emissions by a professional engineer. Along with following the EPA guidelines to prevent air pollution, the NPDES guidelines will be followed to ensure that all discharges of water will not result in any toxic materials. Following the Clean Water Act of 1972, the NPDES permit program is authorized to state governments by the EPA to perform permitting and enforcement of these guidelines. This permitting program will be followed, and the water discharge process will be regularly inspected by a professional engineer to ensure that no toxic materials are being released by water discharge.

OSHA Applicable Standards

In running and designing the plant in question it is important to consider the necessary OSHA implications from the start of the design process to the daily operation and design of standard operating procedures. The 12 steps of process safety to be adhered to are as follows:

- Process Safety Information (PSI) – is often seen as safety data sheets (SDS) but exists in many other forms including plant and process data as well as industry knowledge.
- Process Hazard Analysis (PHA) – are typically completed prior to the start of work to help individuals identify the safety hazards that exist in or around any particular task.
• Management of Change (MOC) – is a form of communication to all employees. This is also implied as safety to be led from ‘the top-down’.

• Pre-Startup Safety Review (PSSR) – can take the shape of visual, mechanical, or other checks prior to the start-up of equipment to ensure the clearance of any hazardous energy. PSSRs are aided by safety interlocks.

• Mechanical Integrity and Plant Reliability (MI&PR) – MI&PR helps to ensure the equipment and other infrastructure that is trusted so readily by employees is truly up to par.

• Operating Procedures (OP) – Ops or often called standard operating procedures are intended to help assist employees in noncommon-knowledge tasks that inherently hold risk.

• Safe Work Practices (SWP) – are specially designed safety procedures on a per-task basis. Often created by safety committees in well-run plants.

• Training and Performance (T&P) – how well training is run speaks to how well a plant is run. These can be lagging indicators for employee retention.

• Contractors (Contractor) – this implies the importance of hazard awareness no matter who is the person near it.

• Emergency Management Plan (EMP) – take place to reduce catastrophes or to effectively respond to incidents.

• Incident Investigation (Incident) – report on any incident often through the ‘5Y’ practice of root-cause analysis.

• Audits (Audit) – take place to ensure all the other steps are in place and to find any gaps in-between programs
COVID-19 Applicable Standards

All guidance set forth by the Western Michigan University College of Engineering and Applied Sciences and the Department of Paper and Chemical Engineering as well as the U.S Centers for Disease Control will be followed. Lacking another force majeure all COVID guidelines set forth by local, state, and federal bodies will be observed through the time period of design, implementation, and all other work to ensure the continued completion of the project and safe environment for others.

MARKET SURVEY

In order to provide a fully successful project overview, it must be first established that there is a market that is existent and will continue to exist in the future regarding the production of midweight to lightweight paper. Also, it must be shown that the paper market is profitable. Finally, this market survey will include a list of assumptions that helped set the parameters for the researched and analyzed data in this market survey.

The assumptions that were made to create the parameters for the market survey in this project were as follows:

- The paper plant is already built, and all equipment is installed (excluding extended nip-press).
- The paper company also a domestic company that only conducts business in the United States.
- The life of the paper plant is only 15 years.
- The plant operates 363 days/calendar year.
- Production level of paper plant is 2000 TPD.
- The paper plant is run using natural gas.
In order to analyze the demand of paper, the consumption of paper of the past 10 years will be analyzed in hopes to create a model to estimate future consumption of paper over the next 10 years.

Figure 23: United States Paper Consumption, Recorded & Predicted [4]

Figure 23 shows the consumption of paper in the United States from years 2006-2018 [4]. The figure also shows the predicted consumption of paper in the United States over the next 10 years until 2030. While a slight decrease in consumption has been observed in past years and future predicted years, but this decrease does not bring a point of concern regarding the product of the project.
The next step in completing a successful market survey is to make sure the fuel being used to run the paper plant is economically sustainable.

![Figure 24: Cost of Natural Gas over the past 20 years [5]](image)

In analyzing the retrieved data above in Figure 24 [5], it can be seen that there is a declining behavior of the average cost of natural gas over the past 15 years. The price of natural gas per therm has fluctuated between $1-$3.50 in the year of 2020. This allows us to believe that future use of this fuel will not negatively impact the paper plant in a sizable way. Further corroboration of this fact is that a conservative estimate of natural gas price of 1$ per therm was used which resulted in the lowest possible projected savings.
EQUIPMENT PRICING & UTILITY COSTS

This section will include general assumptions to provide parameters of our equipment and utility costs, as well as the statement of the costs of the recommended extended nip press and costs of utilities. The assumptions that will be made in this section are as follows:

- The paper drying section is powered by steam created in natural gas boilers at 85% efficiency.
- The cost of natural gas is $.01 per cubic foot [5].
- The paper plant produces 2000 TPD.
- Cost of pulp was found to be about $160/ton assuming high efficiency fiber recovery [6].

Based on industry knowledge, an estimation on the cost of an extended nip press was made to be about $6 million. The cost of operation using natural gas was found to be around $39 million per year.

ECONOMIC ANALYSIS

To ensure that project is economically feasible, an economic analysis was performed. Assumptions that were made can be seen below:

- Life of paper plant is 15 years.
- No downtime costs will be evaluated in this analysis.
- No salvage value for any equipment or property.
- Tax rate is 21% of the profit.
- MARR is assumed to be 20%.
- Working capital is 15% of the fixed capital investment.
- Straight-line depreciation.
Analysis of Scenarios

Basing calculations on the assumption that the current plant produces 2000 Tons of paper per day, energy costs were estimated. Several cost scenario reductions have been provided in Table 1, each scenario distinguishable by an arbitrary value assigned as “Paper weight”. Increasing “Paper weight” values represent “heavier” paper products produced in manufacturing processes. While decreasing “paper weight” values represent “lighter” paper products produced in manufacturing process.

| Table 1 |
| Energy Savings Analysis |

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>1</td>
<td>2000</td>
<td>2.1</td>
<td>4200</td>
<td>3810177</td>
<td>150</td>
<td>10461602.99</td>
<td>12307768.22</td>
<td>37.2591</td>
<td>330329.1873</td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td>2000</td>
<td>1.9</td>
<td>3800</td>
<td>3447503</td>
<td>150</td>
<td>9407259.84</td>
<td>11135599.82</td>
<td>37.2591</td>
<td>298869.2647</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2000</td>
<td>1.8</td>
<td>3600</td>
<td>3265866</td>
<td>150</td>
<td>8967088.276</td>
<td>10549515.62</td>
<td>37.2591</td>
<td>281319.3034</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>2000</td>
<td>1.6</td>
<td>3200</td>
<td>2902992</td>
<td>150</td>
<td>7970745.124</td>
<td>9377247.217</td>
<td>37.2591</td>
<td>256169.3808</td>
</tr>
<tr>
<td>post (% Steam reduction)</td>
<td>1</td>
<td>2000</td>
<td>2.016</td>
<td>4032</td>
<td>3657769.9</td>
<td>150</td>
<td>10043138.87</td>
<td>11815457.49</td>
<td>37.2591</td>
<td>317116.0198</td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td>2000</td>
<td>1.824</td>
<td>3648</td>
<td>3309410.9</td>
<td>150</td>
<td>9086649.453</td>
<td>10690175.83</td>
<td>37.2591</td>
<td>286914.4941</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2000</td>
<td>1.728</td>
<td>3456</td>
<td>3135231.4</td>
<td>150</td>
<td>8608404.745</td>
<td>10127534.99</td>
<td>37.2591</td>
<td>271813.7313</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>2000</td>
<td>1.536</td>
<td>3072</td>
<td>2768672.3</td>
<td>150</td>
<td>7651915.325</td>
<td>9002253.328</td>
<td>37.2591</td>
<td>245161.2596</td>
</tr>
<tr>
<td>Delta</td>
<td>1</td>
<td>2000</td>
<td>-0.076</td>
<td>-152</td>
<td>-137892.1</td>
<td>150</td>
<td>-38610.3939</td>
<td>-44542.992</td>
<td>37.2591</td>
<td>-11954.77059</td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td>2000</td>
<td>-0.072</td>
<td>-144</td>
<td>-136364.6</td>
<td>150</td>
<td>-358683.531</td>
<td>-421980.624</td>
<td>37.2591</td>
<td>-11325.57214</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2000</td>
<td>-0.064</td>
<td>-128</td>
<td>-116119.7</td>
<td>150</td>
<td>-318829.8054</td>
<td>-375093.8887</td>
<td>37.2591</td>
<td>-10087.17523</td>
</tr>
</tbody>
</table>

Reviewing Table 1, the largest energy savings is realized when processing lighter paper products, while the lowest energy savings is realized when processing heavier weight paper. The average daily savings across all product varieties when an extended nip press is added to the production process was calculated to be $3,944.01.

Cash Flow Table

Using the assumption that the only income will be due to the saved energy cost of the reduced natural gas supply, along with the results of the energy analysis table, a cash flow table was created and can be seen below in Table 2.
Table 2

Economic Cash Flow Table

<table>
<thead>
<tr>
<th>BASIS (year)</th>
<th>Plant Life (year)</th>
<th>Depreciation of Equipment (year)</th>
<th>Depreciation of Real Estate (year)</th>
<th>Fixed Capital (Equipment) (MM)</th>
<th>Working Capital (15% of FCI)</th>
<th>Income (MM)</th>
<th>Expenses (MM)</th>
<th>i</th>
<th>MARR (%)</th>
<th>Salvage Value (MM)</th>
<th>Tax Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>15</td>
<td>15</td>
<td>6</td>
<td>0.9</td>
<td>1.4</td>
<td>0</td>
<td>0.1</td>
<td>0.2</td>
<td>0</td>
<td>0.2</td>
<td>0.21</td>
</tr>
</tbody>
</table>

NPV (MM): 1.86362
B/C: 1.460500918
ROI: 250.65%
PBP (year): 4.946470198
IRR: 14%

The goal of this cash flow table is to show the value of this investment, along with the speed at which the savings will equal and surpass the cost of the investment. Assuming the price of paper and the expenses of the paper mill do not significantly change over the course of future years, the yearly savings from Table 1 will be input as the yearly profit value in Table 2. On evaluation of the cash flow Table 2 above the following conclusion were obtained:

- Net present value (NPV) was $1.86 MM.
- Return on Investment (ROI) was 250.68%
- Payback period (PBP) was 4.94 years.
- Internal rate of return (IRR) was 14%
These values show that the recommended replacement of the roller press with the extended nip press into the paper production process is highly favorable.

CONCLUSIONS

In conclusion, the Young’s Modulus simulations using Lattice-Boltzmann techniques, provided results supporting the decrease in water when an extended press nip is integrated into paper production process, instead of a roll press. An extended nip press was evaluated, and a schematic was created showing where this press would replace the roll press in a paper machine. A market analysis was confirmed that there is sufficient demand for paper, and that the cost of natural gas is sustainable as a fuel to power the paper plant. Economically, the proposed upgrade from the roll press to the extended nip-press has been forecasted as a highly favorable investment. The energy savings realized through the reduction in steam usage, has on average been estimated to be $1.4 MM per year. With a fixed capital investment of approximately $6 MM, the yearly savings in energy costs will result in a 251% ROI, 4.9-year payback period, and a 14% internal rate of return.

Summary of all efforts is included in the appendix as meeting minutes.

RECOMMENDATIONS

The next steps that are recommended, are that an extended nip press should replace the roll press in paper machines with these running criteria. For alternative scenarios more analysis should be conducted. Finally, in order to maximize profits, steam efficiency, heat transfer, and other methods of reducing solids content at the press should be considered for similar scenarios. These alternatives may include alterations in wet-end chemistry to achieve better drainage or better retention.

2. "Material Properties 101."
   https://www.youtube.com/channel/UCR1lLEq6UEA_zQ81kwXfg, 6 Oct. 2016,


   2001/#:~:text=This%20statistic%20shows%20the%20total,amounted%20to%2076.77%20million%20tons.


   https://ycharts.com/indicators/us_producer_price_index_pulp_paper_and_allied_products_woodpulp
APPENDICIES

Appendix 1 – Hand Calculations

Reduction of 1\% of water from press
Appendix 2 – Meeting Minutes

Meeting 1

Date: January 11, 2021

To: Omar Kamal Aly, Ian Geiger, Zac Weber, Landon Haight

From: Andrew McCabe

Subject: Introductions and Allocation of Labor Resources

Overview of the meeting

Andrew Proposed the idea of roles to the group over text, nominating himself for notetaker for the semester.

The discussion had led to the following preliminary roles:

- Lead Notetaker: Andrew
- Lead Excel Technician: Zach
- Lead M&EB Coordinators: Ian and Landon
- Lead Researchers: Zach and Omar
- Lead Editors: Landon, Ian, and Andrew

Discussion diverted to potential for the most intriguing topics of design prior to a sudden meeting drop for all members.

Meeting Attendees

Ian Geiger, Zac Weber, Landon Haight, Andrew McCabe

Omar Kamal Aly was currently driving and unable to attend.
Meeting 2

Date: January 17, 2021
To: Dr. Dewei Qi, Dr. James Springstead, Omar Kamal Aly, Ian Geiger, Zac Weber, Landon Haight
From: Andrew McCabe
Subject: Group Member Overview of Linux at Introductory Level

Overview of the meeting

Mr. Weber welcomed each group member into the meeting. Topics covered were:

✔ Downloading Putty
✔ Login into WMU THOR Terminal
✔ Key commands:

<table>
<thead>
<tr>
<th>Command</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>./</td>
<td>“Step-into”</td>
</tr>
<tr>
<td>ls</td>
<td>Print contents of directory</td>
</tr>
<tr>
<td>cd</td>
<td>Change directory</td>
</tr>
<tr>
<td>passwd</td>
<td>Change password</td>
</tr>
<tr>
<td>history</td>
<td>Show history</td>
</tr>
<tr>
<td>clear</td>
<td>Cleans terminal</td>
</tr>
</tbody>
</table>

Once ensuring each member actively reached the current step, Mr. Weber proceeded to the next until each felt they had a brief introductory knowledge of how to navigate Linux.

Meeting Attendees

Ian Geiger, Zac Weber, Landon Haight, Andrew McCabe, Omar Kamal Aly
Meeting 3

Date: January 20, 2021

To: Dr. Dewei Qi, Dr. James Springstead, Omar Kamal Aly, Ian Geiger, Zac Weber, Landon Haight

From: Andrew McCabe

Subject: Linux Walkthrough, Program file Transmission

Meeting Attendees
Dr. Dewei Qi, Ian Geiger, Landon Haight, Andrew McCabe, Omar Kamal Aly

Mr. Weber was unable to attend due to a recent surgery.

1. Approval of Minutes
   Approval received over email.

2. Weekly Progress
   It is noted that all have gained access to Linux prior with the exception of Mr. Kamal due to technical issues.

3. Discussion/Clarification
   Dr. Qi welcomed group into meeting. Inquired about Mr. Weber and was informed by all of his current surgery.

   Dr. Qi guided members of the group through the two research papers in an effort to explain the way in which his current code operates. The former of which models roughly 18 fibers with the Lattice Boltzmann method, the latter

   Mr. McCabe asked about the nature of the fibers intersecting if there was a form of intersection boundary. Dr. Qi notes the first paper did not model this but the second does limit fiber-to-fiber intersection art the surface of each fiber with a repulsion force.

   Dr. Qi, not wanting the students to get too far ahead of themselves, sought to continue with Linux. He lead the students to three files, “fluid.inp”, “solid.inp”, and “sdprest.f”, which they must copy from his directory and input into their own.

   Mr. Geiger noted we are having issues getting files to upload to Linux using Putty. Dr. Qi decided it was best we utilized a program he owns, “SSH Secure File Transfer Client”. Once each member was able to upload the 3 files into their Thor terminal Dr. Qi proceeded.

   Upon working in the Thor terminal with the new code, Dr. Qi navigated each team member present through some basic commands. These can be seen below in a reference table (prior commands are saved for reference as well).

<table>
<thead>
<tr>
<th>Command</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>./</td>
<td>“Step-into”</td>
</tr>
<tr>
<td>Command</td>
<td>Description</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------------------------------------------------</td>
</tr>
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<td>Print contents of directory</td>
</tr>
<tr>
<td>cd</td>
<td>Change directory</td>
</tr>
<tr>
<td>passwd</td>
<td>Change password</td>
</tr>
<tr>
<td>history</td>
<td>Show history</td>
</tr>
<tr>
<td>clear</td>
<td>Cleans terminal</td>
</tr>
<tr>
<td>cp</td>
<td>Copy said file to destination</td>
</tr>
<tr>
<td>rm</td>
<td>Remove said file</td>
</tr>
<tr>
<td>man</td>
<td>Help</td>
</tr>
<tr>
<td>ps -a</td>
<td>Displays what is running in the foreground</td>
</tr>
<tr>
<td>ctrl + c</td>
<td>Stops current running process</td>
</tr>
<tr>
<td>mkdir</td>
<td>Makes a directory (like a folder)</td>
</tr>
<tr>
<td>ls -lt</td>
<td>Lists all in present directory</td>
</tr>
<tr>
<td>gfortran</td>
<td>Runs Said file with Fortran</td>
</tr>
<tr>
<td>e.g. (gfortran sdprest.f -o2)</td>
<td>to run program with optimizer</td>
</tr>
<tr>
<td>vi</td>
<td>Opens text editor ‘Vim’</td>
</tr>
<tr>
<td>:w</td>
<td>Write (Save File)</td>
</tr>
<tr>
<td>:wq</td>
<td>Write and quit</td>
</tr>
<tr>
<td>:q!</td>
<td>Quits without saving</td>
</tr>
</tbody>
</table>

Dr. Qi says this work has gotten former students published prior. We would have to work hard to achieve that. Mr. Omar and Mr. McCabe express interest in being published.

Mr. McCabe asked about the nature of the jet-to-wire speed difference. Dr. Qi notes that this is currently in his program at a 1:1 ratio but can be changed. Dr. Qi notes this would be a good topic of design interest. Additionally, fiber length distribution variance, wire size, amongst other topics.

Mr. McCabe recommends the group meet, as it similarly has on the Linux specific subject matter, to discuss paper science fundamentals that are applicable to this course.

All scheduled to meet again on 1/27 at 11:30 am.

4. **Action Items**
Mr. Haight to upload meeting recording and share link with all.

Mr. Haight is to draft an email to Dr. Li and Dr. DeDoncker requesting access to Tec.

Mr. McCabe is to arrange a meeting at the Paper Pilot Plants with Mr. Pschigoda.

Mr. Kamal is sourcing a laptop more suitable for this purpose.

All, except for Mr. Weber and Dr. Qi, met to overview content learned today.

All will practice Linux commands.
Meeting 4

Date: January 21, 2021

To: Dr. Dewei Qi, Dr. James Springstead, Omar Kamal Aly, Ian Geiger, Zac Weber, Landon Haight

From: Andrew McCabe

Subject: Paper Pilot Plant Machine Walkthrough with Mr. Lon Pschigoda

Meeting Attendees

Mr. Lon, Pschigoda, Mr. Geiger, Mr. Haight, Mr. McCabe

Mr. Weber was unable to attend due to a recent surgery. And Mr. Kamal due to a prior work commitment.

1. **Approval of Minutes**
   Approval received over email.

2. **Weekly Progress**
   This meeting is being held as a follow-up to the 1/20/2021 meeting with Dr. Qi to clarify basic paper principals.

3. **Discussion/Clarification**
   Mr. Lon Pschigoda was gracious enough to allow our team to walk ourselves through the WMU Paper Pilot Plants. Here Mr. McCabe explained introductory paper concepts to the group.

Group members scheduled to meet again on 1/24 at 8:00 p.m. and subsequently all project members are scheduled to meet on 1/17 at 11:30

4. **Action Items**
   Attend further meetings.
Meeting 5

Date: January 24, 2021

To: Dr. Dewei Qi, Dr. James Springstead, Omar Kamal Aly, Ian Geiger, Zac Weber, Landon Haight

From: Andrew McCabe

Subject: Group Progress Meeting and Catch-Up

Meeting Attendees

Mr. Weber, Mr. Geiger, Mr. Haight, Mr. Kamal

Mr. McCabe was unable to attend due to a prior commitment.

1. Approval of Minutes and Action Item Review
   Approved.

2. Weekly Progress
   All members walked through Linux commands learned this past week to successfully download files created by Fortran command. All are ready to begin viewing files in Tecplot and subsequently editing files using vim commands.

3. Discussion/Clarification
   Refer to below for reference commands:

<table>
<thead>
<tr>
<th>Command</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>./</td>
<td>“Step-into”</td>
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<td>cd</td>
<td>Change directory</td>
</tr>
<tr>
<td>passwd</td>
<td>Change password</td>
</tr>
<tr>
<td>history</td>
<td>Show history</td>
</tr>
<tr>
<td>clear</td>
<td>Cleans terminal</td>
</tr>
<tr>
<td>cp</td>
<td>Copy said file to destination</td>
</tr>
<tr>
<td>rm</td>
<td>Remove said file</td>
</tr>
<tr>
<td>man</td>
<td>Help</td>
</tr>
<tr>
<td>ps -a</td>
<td>Displays what is running in the foreground</td>
</tr>
<tr>
<td>ctrl + c</td>
<td>Stops current running process</td>
</tr>
<tr>
<td>Command</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td>mkdir</td>
<td>Makes a directory (like a folder)</td>
</tr>
<tr>
<td>ls -lt</td>
<td>Lists all in present directory</td>
</tr>
<tr>
<td>gfortran</td>
<td>Runs Said file with Fortran</td>
</tr>
<tr>
<td></td>
<td>e.g. (gfortran sdprest.f -o2) to run program with optimizer</td>
</tr>
<tr>
<td>vi</td>
<td>Opens text editor vim*</td>
</tr>
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<td>Write (Save File)</td>
</tr>
<tr>
<td>:wq</td>
<td>Write and quit</td>
</tr>
<tr>
<td>:q!</td>
<td>Quits without saving</td>
</tr>
</tbody>
</table>

- Further vim commands can be learned through the following link (https://www.radford.edu/~mhtay/CPSC120/VIM_Editor_Commands.htm)

All scheduled to meet again on 1/27 at 11:30 am.

4. **Action Items**

Meet at 1/27/2021 at 11:30 am.
Meeting 6

Date: February 3, 2021

To: Dr. Dewei Qi, Dr. James Springstead, Omar Kamal Aly, Ian Geiger, Zac Weber, Landon Haight

From: Andrew McCabe

Subject: Group Progress Meeting and Catch-Up

Meeting Attendees
Dr. Qi, Mr. Weber, Mr. Geiger, Mr. Haight, Mr. McCabe

Mr. Kamal was unable to attend due to meeting to be hired full-time at his new career.

1. Approval of Minutes and Action Item Review
Approved.

2. Weekly Progress
Team was introduced to background running processes and set on a path to retrieve files for modelling press-section fiber mat compression.

3. Discussion/Clarification
   - Dr. Qi discussed pressure curve found in wet press section. This involved the two press rolls applying a loading force to the sheet, units are pounds per linear inch (PLI) typically. Discussed different press-loading curves for shoe versus typical roll press.
   - SweetMcdonald.pdf file shared prior discusses rewetting and fit model made by Sweet, this originates from the 1960’s.
   - Formula used:
     \[ m = m_r + \frac{R}{W} \]  ;where, m is the moisture ratio after the nip, \( m_r \), R is the amount of water reabsorbed or ‘Rewet’, and W is the oven dry basis weight.
   - Background running processes were introduced more formally. Necessary commands have been added to the bottom of the command list:

<table>
<thead>
<tr>
<th>Command</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>./</td>
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<td>Cleans terminal</td>
</tr>
<tr>
<td>Command</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td><strong>cp</strong></td>
<td>Copy said file to destination</td>
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<tr>
<td><strong>:wq</strong></td>
<td>Write and quit</td>
</tr>
<tr>
<td><strong>:q!</strong></td>
<td>Quits without saving</td>
</tr>
<tr>
<td><strong>qsub</strong></td>
<td>Runs a script</td>
</tr>
<tr>
<td><strong>qdel</strong></td>
<td>Deletes background running process in the commands list</td>
</tr>
<tr>
<td><strong>qstat</strong></td>
<td>Provides status of background running process</td>
</tr>
</tbody>
</table>

- New press-section files were also given a location to files from.

### 4. Action Items
All scheduled to meet again on 2/10 at 11:30 am.

Students set to meet again 2/8 at 5:00 pm and try to get output to work

**Reference Photos**
rectangle
solidcoef.dat
120
1.25
1.0
1 1 0
0.1
30
2 2 30
1.3
2.5 4.0 2.5 8.06E-4
5.5 200 11000 1.0 0.0
shape
number_of_solid
solid_density
bond_length
switch_spr, switch_ang, switch_FENE
Young's modulus (dimensionless)
solid_cycle_times (default=30)
pa, pb, pc, pc_index_driven
\( \varepsilon \) \( \varepsilon \) (ellipsoid=1, RBC=20)
CUTR, RL, sigma, epsolin
TWODIS IT1 PERT AA1 ZZ0
"solid.inp" 12L, 657C
Meeting 7

Date: February 10, 2021

To: Dr. Dewei Qi, Dr. James Springstead, Omar Kamal Aly, Ian Geiger, Zac Weber, Landon Haight

From: Andrew McCabe

Subject: Group Progress Meeting and Catch-Up

Meeting Attendees

Dr. Qi, Mr. Weber, Mr. Geiger, Mr. Haight, Mr. Kamal, Mr. McCabe

1. Approval of Minutes and Action Item Review

   Approved.

2. Weekly Progress

   Team was introduced to background running processes and set on a path to retrieve files for modelling press-section fiber mat compression.

3. Discussion/Clarification

   Jobs will be split based upon the number of fibers in the model. Jobs will be delineated as:

   F500 – Andrew
   F380 – Zac
   F260 – Landon
   F160 – Ian
   F080 – Omar

   Dr. Qi will present on May 18th, there may be a presentation in October. Data should be ready in three weeks’ time at the latest. By March 1st.

   Make new directory with name of Fiber.

   Copy files from Chris:

   scp ysf2057@thor.cs.wmich.edu:~/210203/Press/F500/sdpres .
   scp ysf2057@thor.cs.wmich.edu:~/210203/Press/F500/sdpres.f .
   scp ysf2057@thor.cs.wmich.edu:~/210203/Press/F500/sdpres1.inp .
   scp ysf2057@thor.cs.wmich.edu:~/210203/Press/F500/sdpres2.inp .
   scp ysf2057@thor.cs.wmich.edu:~/210203/Press/F500/solidcof.dat .
   scp ysf2057@thor.cs.wmich.edu:~/210203/Press/F500/SRPULSE.dat .
   scp ysf2057@thor.cs.wmich.edu:~/210203/Press/F500/script.sh .
sdpres1.inp should have lines as follows, do not change the x, y, and Z size. Change ‘amountfluidfield’ to 40:

```plaintext
Sdpres2.inp the fiber numbers should correspond to each individual’s number of fibers. Sdpres2.inp is to have the young’s modulus changed (0.1):
```
Start compiling:

Gfortran -o sdpres sdpres.f -o2

Front running is not allowed; therefore, we use script to run in background.

vi script.sh:

```
#!/bin/sh

#PBS -j oe
#PBS -l nodes=1
#PBS -l walltime=990:90:00

cd /home/pi/vyj4986/F500/sdpres

./sdpres
```

Save with “:wq!”

Submit job to run in background with qsub. Qstat to check runability. Qdel to delete job.

Copy files:

```
cp ./F500/*
cp ~/F500/* ~/F500_2/
```

Sdpres2.inp is to have the young’s modulus changed (.005):
Run with script.sh file after you change it to:

```
#!/bin/sh

#PBS -j oe
#PBS -l nodes=1
#PBS -l walltime=990:90:00

cd /home/pi/vyj4986/F500_2/sdpres

./sdpres
```

**Research Review**

Dr. Qi shared the research paper, “Lattice-Boltzmann lattice spring simulations of wet press at individual fiber level”.

**4. Action Items**

All scheduled to meet again on 2/17 at 11:30 am.

Students should run their jobs preferably by next week - this is dependent upon processing power and availability of the server.

**Reference Commands**
<table>
<thead>
<tr>
<th>Command</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>./</td>
<td>“Step-into”</td>
</tr>
<tr>
<td>ls</td>
<td>Print contents of directory</td>
</tr>
<tr>
<td>cd</td>
<td>Change directory</td>
</tr>
<tr>
<td>passwd</td>
<td>Change password</td>
</tr>
<tr>
<td>history</td>
<td>Show history</td>
</tr>
<tr>
<td>clear</td>
<td>Cleans terminal</td>
</tr>
<tr>
<td>cp</td>
<td>Copy said file to destination</td>
</tr>
<tr>
<td>rm</td>
<td>Remove said file</td>
</tr>
<tr>
<td>man</td>
<td>Help</td>
</tr>
<tr>
<td>ps -a</td>
<td>Displays what is running in the foreground</td>
</tr>
<tr>
<td>ctrl + c</td>
<td>Stops current running process</td>
</tr>
<tr>
<td>mkdir</td>
<td>Makes a directory (like a folder)</td>
</tr>
<tr>
<td>ls -lt</td>
<td>Lists all in present directory</td>
</tr>
<tr>
<td>gfortran</td>
<td>Runs Said file with Fortran</td>
</tr>
<tr>
<td></td>
<td>e.g. (gfortran sdprest.f -o2) to run program with optimizer</td>
</tr>
<tr>
<td>vi</td>
<td>Opens text editor vim*</td>
</tr>
<tr>
<td>:w</td>
<td>Write (Save File)</td>
</tr>
<tr>
<td>:wq</td>
<td>Write and quit</td>
</tr>
<tr>
<td>:q!</td>
<td>Quits without saving</td>
</tr>
<tr>
<td>qsub</td>
<td>Runs a script</td>
</tr>
<tr>
<td></td>
<td>e.g. (qsub script.sh) to run script.sh</td>
</tr>
<tr>
<td>qdel</td>
<td>Deletes background running process in the commands list</td>
</tr>
<tr>
<td>qstat</td>
<td>Provides status of background running process</td>
</tr>
</tbody>
</table>
Reference Photos

```
LBM+LSM+EBF
try.out
try.cof
60 60 250
0
1 1 0
1 1 1
0 0 0
1.0 1.0
0.001 0.08
0.0 0.000 0.0 0.0
1 2000
0.001 1.0000
-0.0 0.0 0.0
32
0.0080645 1.0000
0.005 1.000000
0.01 1.0
0.0738061176 1.0
0.0025 1.000000
0.0080645 1.000000

name
output.log

nx, ny, nz
LOAD_RECORD

s_0_Re, s_g_s_shearflow
periodic_boundary for (l=period)
periodic_boundary for wall (l=period)
fdgn rfden
smu, rmu

vb1, vb2, pres2_pressure U0

i_s, f_s, p_s_print, r_s_d, p_s_g_0

d, d
theta, phi, psi

amountfluid4leid DZ0 ID0

d, d

12, 8

Connected to thor.cs.wmich.edu
```
rectangle
solidconf.dat
solidcof2.dat
SRPULSE.dat

30 4 3 3
1.2 1.01 1.00
1.0
1.1 0
0.1 0.005 0.005
30
2 2 20
1.3
3.0 4.0 3.0 8.06E-6
3.8 1 200 1.0
33 35 38 40 10 3 3
31 10 3 3
32 10 3 3 20
1 -0.01 200 0.0

shape

number_of_solid NUMFELT NBONDTYPE NANGLETYP

solid density(3)

bond length

switch_spr, switch_ang, switch_FENE

Young's modulus (3)

solid_cycle_times(default=30)

pa, pb, pc, pc_index_driven

er(ellipsoid=1, RBC=20)

CUTR, RL, sigma, epsolln

TWDIS TII PERT AAI (4 iparticle dis)

FELMIN1 FELMAX1 FELMIN2 FELMAX2 FELTJUMP IFWIDTH JFWIDTH

WIER1 WJUMP1 IWIDTH1 JWIDTH1

WIER2 WJUMP2 IWIDTH2 JWIDTH2 WIRESTP

FRES_SWITCH FRESZ TFRESS D2
Meeting 8

**Date:** February 17, 2021

**To:** Dr. Dewei Qi, Dr. James Springstead, Omar Kamal Aly, Ian Geiger, Zac Weber, Landon Haight

**From:** Andrew McCabe

**Subject:** Group Progress Meeting

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**Meeting Attendees**

Dr. Qi, Mr. Weber, Mr. Geiger, Mr. Haight, Mr. Kamal, Mr. McCabe

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1. **Approval of Minutes and Action Item Review**

   Approved.

2. **Weekly Progress**

   Team was introduced to how to determine if output is valid as well as how to view graphical output. Introduction to Tecplot concepts and prep for next week. Assignment to each team member to graph their output data.

3. **Discussion/ Clarification**

   **Economic analysis**

   Economics will be based on the assumption of removing merely 1% moisture content of water from paper web leaving the press section. It is common industry knowledge that every 1% reduction in water here results in 4% reduction in process cost due to reduction in steam load. Considering this, students should begin creating an economic analysis and material balance centered around the wet press of a paper machine to illustrate the amount of energy reduction potential.

   **New Commands**

   Make new directory with name of Calculation.

   Copy files from Chris:

   ```
   scp ysf2057@thor.cs.wmich.edu:~/210203/Cal/*.f .
   scp ysf2057@thor.cs.wmich.edu:~/210203/Cal/read.inp .
   scp ysf2057@thor.cs.wmich.edu:~/210203/Cal/solid.dat .
   ```

   **With these files in the Calculation folder, we can copy files from WHERE to input out calculated data.**

   With all the needed files in the same folder, the command below can be run to compile the files:

   ```
   Gfortran readfeltv2.f -O2
   ```
Once compiled the files can be checked with the below vi commands to look to make sure the data from the new ‘read.inp” file matches our existing “sdpres2.inp” information.

vi sdpres2.inp
vi read.inp
Output of data will be in the following form, where the columns correspond to time stamp intervals of 20, thickness, concentration, moisture ration, and felt thickness.
4. **Action Items**

All scheduled to meet again on 2/21 at 11:30 am.

Students should run the analysis of jobs by next week so they can run Tecplot.
Meeting 9

**Date:** February 24, 2021

**To:** Dr. Dewei Qi, Dr. James Springstead, Omar Kamal Aly, Ian Geiger, Zac Weber, Landon Haight

**From:** Andrew McCabe

**Subject:** Group Progress Meeting

Meeting Attendees

Dr. Qi, Mr. Weber, Mr. Geiger, Mr. Haight, Mr. Kamal, Mr. McCabe

1. **Approval of Minutes and Action Item Review**
   Approved.

2. **Weekly Progress**
   Team practiced to how to determine if output is valid as well as how to view graphical output. Waiting for Tecplot.

3. **Discussion/Clarification**
   **Practice of Output Processing Commands**
   Add the below files from Chris into corresponding test folder with output data (e.g. F80, F380_2 etc.)

   Copy files from Chris:
   
   scp ysf2057@thor.cs.wmich.edu:~/210203/Cal/readfeltv2.f .
   scp ysf2057@thor.cs.wmich.edu:~/210203/Cal/read.inp .

   With all the needed files in the same folder, the command below can be run to compile the files:

   Gfortran readfeltv2.f -O2

   Once compiled the files can be checked with the below vi commands to look to make sure the data from the new ‘read.inp” file matches our existing “sdpres2.inp” information. See reference appendices for what to expect.

   vi sdpres2.inp
   vi read.inp

   Preliminary pressure output will in the file prest1.dat. From here, the file can be transferred to a local computer through ‘SSH Secure File Transfer’. Save the file as a .txt file after opening it in ‘Notepad’. Open with excel and processing accordingly results in the below graph:
Final output of data is still processing due to high computational demand. Once available, these will be processed with the similar method from the ‘calthickness.dat’ file. Rows in output correspond to time stamp intervals of 20, thickness, concentration, moisture ration, and felt thickness. Reference units can be found in Appendices as well.

4. **Action Items**
All scheduled to meet again on 3/3 at 11:30 am.

Dr. Qi to give talk on said data on March 6th.
Reference Vi.inp Files

Reference Units
EI = 8.53333587646488E-004
EI  = 4.266666793823243E-005
(\text{g'/cm}^3/\text{s}^2)
Reynolds number = 0.0000000000000000E+000

EI = 0.13333325386047
EI = 6.66666626930236E-003
EI = 6.66666645348816E-003
Reduced EIR = Infinity
Reynolds number = 0.0000000000000000E+000

UL(cm), UH(s) = 1.000000000000000E-003
1.250000000000000E-008
UMU(cm^2/s) = 80.000000000000000
UV(cm/s), UHU(cm/s^2) = 640000000000.000
UNASS (g), UBM(g/cm^3) = 1.000000000000000E-009
UAREA(cm^2) = 1.000000000000000E-006
UFORCE (g/cm/s^2) = 6400.000000000000
UFRISE (g/cm/s^2) = 640000000000.000
UFRESS (Kg/m/\text{s}^2) = 6400000005.536743
UFRISE (g/cm/s^2) = 6400000000.00000
GCH = 1.3328212350000000E-010
aspect ratio = 10.000000000000000
Appendix 3 – Meeting Agendas

Meeting 1

Date: January 14, 2021

To: Dr. Dewei Qi, Dr. James Springstead, Landon Haight, Omar Kamal Aly, Ian Geiger, Zac Weber

From: Andrew McCabe

Subject: Agenda for 1/21/2021 Meeting - Introductions and Allocation of Labor Resources

Recap of On-going Topics

1. Team requests overview of project from Dr. Qi.
   a. Will Team need to perform an economic analysis with this project?

2. Discussion of necessary technical abilities.
   a. Zac is familiar with Linux, Andrew with Python.
   b. Team has met and discussed entry into Linux program necessary to work with Dr. Qi’s research. Dr. DeDoncker has delivered ‘Thor’ account names and passwords to each team member.
      i. Has each member tried their account?
   c. Is a fundamental understanding of paper machinery / fluid flows necessary?
   d. Has each member read provide research?

3. Additional

Meeting Attendees

☐ Dr. Dewei Qi
☐ Ian Geiger
☐ Zac Weber
☐ Landon Haight
☐ Andrew McCabe
☐ Omar Kamal Aly

Optional Attendees

☐ Dr. James Springstead
Meeting 2

Date: January 24, 2021

To: Dr. Dewei Qi, Dr. James Springstead, Ian Geiger, Landon Haight, Omar Kamal Aly, Andrew McCabe, Zac Weber

From: Andrew McCabe

Subject: Group Meeting Agenda Scheduled for 1/27/2021

Expected Meeting Attendees
Dr. Qi, Mr. Geiger, Mr. Haight, Mr. Kamal, Mr. McCabe, Mr. Weber

Optional Meeting Attendees
Dr. Springstead

1. Approval of Minutes
Approved.

2. Weekly Progress
Mr. Haight found video recording corrupted and was unable to upload 1/20/2021 meeting.

Mr. Haight has is awaiting student price for Tecplot.

Mr. McCabe, Mr. Haight, and Mr. Geiger toured Paper Pilot Plants with Mr. Pschigoda.

Mr. Kamal has sourced a new laptop.

All members walked through Linux commands learned this past week to successfully download files created by Fortran command.

All are ready to begin viewing files in Tecplot and subsequently editing files using vim commands.

Mr. McCabe spoke to Dr. Springstead and economic analysis model will be required.

3. Discussion/ Clarification
Discussion of potential research topics:

- Jet to wire speed ratio variance model
- Fiber-length distribution model
- Wire / mesh drainage model

Research review / search

Program operation, foreground and background running programs on university servers.

4. Action Items
All scheduled to meet again on 2/3/2021 at 11:30 am.

Practice executing commands to run Tecplot. Review Research
Meeting 3

**Date:** February 1st, 2021

**To:** Dr. Dewei Qi, Dr. James Springstead, Ian Geiger, Landon Haight, Omar Kamal Aly, Andrew McCabe, Zac Weber

**From:** Andrew McCabe

**Subject:** Group Meeting Agenda Scheduled for 2/3/2021

**Expected Meeting Attendees**
Dr. Qi, Mr. Geiger, Mr. Haight, Mr. Kamal, Mr. McCabe, Mr. Weber

**Optional Meeting Attendees**
Dr. Springstead

1. **Approval of Minutes**
   - Approved.

2. **Weekly Progress**
   - All should have read McDonald research shared by Dr. Qi on January 30.

3. **Discussion/ Clarification**
   - Research review.
   - Program operation, foreground and background running programs on university servers.
   - Tecplot license.

4. **Action Items**
   - All scheduled to meet again on 2/10/2021 at 11:30 am.
   - Practice executing commands to run Tecplot.
Meeting 4

Date: February 9th, 2021

To: Dr. Dewei Qi, Dr. James Springstead, Ian Geiger, Landon Haight, Omar Kamal Aly, Andrew McCabe, Zac Weber

From: Andrew McCabe

Subject: Group Meeting Agenda Scheduled for 2/10/2021

Expected Meeting Attendees
Dr. Qi, Mr. Geiger, Mr. Haight, Mr. Kamal, Mr. McCabe, Mr. Weber

Optional Meeting Attendees
Dr. Springstead

1. Approval of Minutes
Approved.

2. Weekly Progress
All should have read McDonald research shared by Dr. Qi on January 30.

3. Discussion/ Clarification
Research review.
Program operation, foreground and background running programs on university servers.
Tekplot license.

4. Action Items
All scheduled to meet again on 2/17/2021 at 11:30 am.
Practice executing commands to run Tekplot.
Meeting 5

Date: February 14th, 2021

To: Dr. Dewei Qi, Dr. James Springstead, Ian Geiger, Landon Haight, Omar Kamal Aly, Andrew McCabe, Zac Weber

From: Andrew McCabe

Subject: Group Meeting Agenda Scheduled for 2/17/2021

Expected Meeting Attendees

Dr. Qi, Mr. Geiger, Mr. Haight, Mr. Kamal, Mr. McCabe, Mr. Weber

Optional Meeting Attendees

Dr. Springstead

1. Approval of Minutes
   Approved.

2. Weekly Progress
   All should have gotten press-section model to run in background on WMU’s, ‘thor.cs.wmich.edu’, server. Passwords should have been saved as decided-upon shared password using ‘passwd’ command.

3. Discussion/ Clarification
   • Introduction of Tecplot and license assignment.
   • Discussion of relevant ‘sdpres’ program output and application of output files.
   • Determination of timelines for all members to run programs.
   • Discussion of economics.

4. Action Items
   All scheduled to meet again on 2/21/2021 at 11:30 am.
Meeting 6

Date: March 3, 2021

To: Dr. Dewei Qi, Dr. James Springstead, Ian Geiger, Landon Haight, Omar Kamal Aly, Andrew McCabe, Zac Weber

From: Andrew McCabe

Subject: Group Meeting Agenda Scheduled for 3/3/2021

Expected Meeting Attendees
Dr. Qi, Mr. Geiger, Mr. Haight, Mr. Kamal, Mr. McCabe, Mr. Weber

Optional Meeting Attendees
Dr. Springstead

1. Approval of Minutes
Approved.

2. Weekly Progress
   Attempt to run output data in Tecplot – awaiting Tecplot license from department.

3. Discussion/ Clarification
   - Introduction of Tecplot and license assignment.
   - Discussion of relevant ‘sdpres’ program output and application of output files.
   - Discussion of economics.

4. Action Items
   All scheduled to meet again on 3/10/2021 at 11:30 am.