The Behaviors of VOC's in Kraft Mills
Part I: Measurement Methods for the Quantification of the
Contents and Vapor-Liquid Phase Partitioning of VOC's

J.Y. Zhu, X.S. Chai, and B. Dhasmana

October 1997

Submitted to
Tappi Journal

Copyright® 1997 by the Institute of Paper Science and Technology

For Members Only
INSTITUTE OF PAPER SCIENCE AND TECHNOLOGY
PURPOSE AND MISSIONS

The Institute of Paper Science and Technology is a unique organization whose charitable, educational, and scientific purpose evolves from the singular relationship between the Institute and the pulp and paper industry which has existed since 1929. The purpose of the Institute is fulfilled through three missions, which are:

- to provide high quality students with a multidisciplinary graduate educational experience which is of the highest standard of excellence recognized by the national academic community and which enables them to perform to their maximum potential in a society with a technological base; and

- to sustain an international position of leadership in dynamic scientific research which is participated in by both students and faculty and which is focused on areas of significance to the pulp and paper industry; and

- to contribute to the economic and technical well-being of the nation through innovative educational, informational, and technical services.

ACCREDITATION

The Institute of Paper Science and Technology is accredited by the Commission on Colleges of the Southern Association of Colleges and Schools to award the Master of Science and Doctor of Philosophy degrees.

NOTICE AND DISCLAIMER

The Institute of Paper Science and Technology (IPST) has provided a high standard of professional service and has put forth its best efforts within the time and funds available for this project. The information and conclusions are advisory and are intended only for internal use by any company who may receive this report. Each company must decide for itself the best approach to solving any problems it may have and how, or whether, this reported information should be considered in its approach.

IPST does not recommend particular products, procedures, materials, or service. These are included only in the interest of completeness within a laboratory context and budgetary constraint. Actual products, procedures, materials, and services used may differ and are peculiar to the operations of each company.

In no event shall IPST or its employees and agents have any obligation or liability for damages including, but not limited to, consequential damages arising out of or in connection with any company's use of or inability to use the reported information. IPST provides no warranty or guaranty of results.

The Institute of Paper Science and Technology assures equal opportunity to all qualified persons without regard to race, color, religion, sex, national origin, age, disability, marital status, or Vietnam era veterans status in the admission to, participation in, treatment of, or employment in the programs and activities which the Institute operates.
The Behaviors of VOC’s in Kraft Mills
Part I: Measurement Methods for the Quantification of the Contents and Vapor-Liquid Phase Partitioning of VOC’s

J.Y. Zhu*, X.S. Chai, and B. Dhasmana
Institute of Paper Science and Technology
500 10th Street, N.W.
Atlanta, GA 30318

ABSTRACT

The understanding of VOC behaviours in Kraft mill streams is important to predict and control mill VOC emissions. Under the DOE sponsorship through the Agenda 2020 program, we conducted this series of a two-part study to understand VOC behaviours in Kraft mills: method development, VOC formation during pulping, and VOC vapor-liquid partitioning. In Part I of this study, we report on the analytical methods for the development of a database that describes both the contents and the vapor-liquid equilibrium partitioning of VOC’s in various Kraft mill streams using a commercial headspace gas chromatography system. The methods are indirect, rapid, accurate, and automated. Preliminary measurements of VOC contents and Henry’s constant of VOC’s in various mill streams are conducted using the developed methods.

Application:
Analysis of VOC content and VLE partitioning in mill and environmental streams

Keywords:
VOC, Henry’s law, vapor-liquid partitioning, headspace, GC, black liquor, mill streams.

* Author to whom correspondence should be addressed
INTRODUCTION

With the increasingly restrictive environmental regulations, maintaining environmentally sound and technologically competitive operations in pulp and paper mills is the key to the success of the U.S. pulp and paper industry. The new toxic and permit provisions of the 1990 amendments require information on emissions of volatile organic compounds (VOC's) from pulp and paper mill sources. Many VOC's are now considered hazardous air pollutants (HAP's). Several studies on VOC emissions at Kraft mills have been conducted. Venketesh et al. [1] reported a millwide VOC prediction using a process simulation technique. The National Council of the Paper Industry for Air and Stream Improvement (NCASI) conducted a series of studies on VOC emissions at Kraft mills. NCASI's studies indicated that the release of VOC's during mill operations is determined by several factors [2]: (1) the VOC content in mill streams, (2) the fundamental thermodynamic vapor-liquid phase equilibrium behavior of the VOC's in mill streams, (3) the mass transfer associated with specific mill processes, and (4) the mill operating conditions, such as wood species, pulping chemicals used, water reuse in operation, etc. Some of the factors pertain to unit operating conditions and specific mill processes such as mass transfer in a unit operation. It is very difficult to generalize all the specific situations. However, the thermodynamic behavior of the VOC's should not depend on the characteristics of specific unit operations. Therefore, it is important to be able to measure VOC content in mill streams and understand the thermodynamic behavior of vapor-liquid phase equilibrium for computer model predictions.

It is not trivial to analyze samples from various mill streams using conventional direct analytical methods with delicate laboratory instruments through calibration because some of the mill streams are corrosive in nature. Gunshefki and Cloutier [3] developed a method to measure
MeOH contents in black liquor. However, their method modifies the sample matrix through the addition of chemicals to precipitate the solids in weak black liquors. The method has several disadvantages: (1) the amount of chemicals added (mass ratio of chemical over black liquor = 30:1) significantly dilutes the VOC concentration in the sample and reduces the measurement accuracy; (2) the method is only suitable for the analysis of weak black liquors as the solid precipitation method may not be used for other mill streams; and (3) the method is tedious, time-consuming, and not applicable for on-line analysis.

There are many methods available to study vapor-liquid phase equilibrium. Mackay and Shiu [4] presented a comprehensive review of the common methods to measure Henry’s constants and their respective merits and deficiencies. Turner et al. [5] and Sherman et al. [6] separately presented their own comprehensive reviews of various methods for vapor-liquid equilibrium (VLE) studies—along with detailed comparisons of VLE data of aqueous organic systems obtained using these methods. Sherman et al. [6] also presented application limits of various available methods for VLE studies. The headspace gas chromatographic (HSGC) method gives a direct quantitative analysis of the vapor of a liquid sample matrix and therefore is very suitable for VLE studies. Much research on vapor-liquid phase equilibrium has been conducted using headspace GC systems [7-10]. The traditional HSGC method [7-10] for vapor-liquid equilibrium study requires quantitative determination of the equilibrium solute concentration both in the vapor and in the liquid phase through direct measurements using error-producing calibration procedures. To obtain experimental simplicity and high accuracy for practical applications, automated indirect HSGC methods will be desirable. Unfortunately, most of the existing indirect HSGC methods have practical difficulties to implement [11]. In this study, we report on the development of indirect methods for rapid, automated, and precise
determination of the contents and the vapor-liquid phase equilibrium partitioning of VOC's in mill streams using a commercial headspace gas chromatography system.

**METHODOLOGY**

*Quantification of VOC Contents in Kraft Mill Streams*

We developed an indirect measurement method for the quantification of VOC contents in liquids by headspace gas chromatography based on the thermodynamic vapor-liquid phase equilibrium. The method is schematically described in Fig. 1. We use two sample vials both filled with the same amount of sample solution. Then, we add a known small amount of concentrated solution into one of the vials. The volume of the solution added is very small compared with the volume of the original solution and therefore can be neglected. We conduct headspace GC analysis of each sample after a phase equilibrium was established within each vial. We can assume that the solute concentrations in these two sample vials are still very low or the solute concentrations are under infinite dilution, which is valid for most VOC’s in mill streams even after the addition. Therefore, the solute VLE partitioning coefficients in these two vials are equal to the Henry’s constant of the solute under consideration, which connects the two independent headspace measurements to determine the solute content in the original sample. The following is the derivation of the present HSGC method.

When a sample solution of volume $V_i^0$ with an unknown solute concentration of $C_0$ is introduced into a closed vial, the amount of solutes in the vapor at vapor-liquid phase equilibrium state can be described as:

$$n_1 = C_0 V_i^0 - \alpha c_i V_i^0 = C_g V_g^0,$$

(1)
where \( C \) and \( C_g \) are the solute concentrations in the liquid and vapor under equilibrium, respectively, \( \alpha \) is the solution volume expansion factor due to temperature change from state 0 to state 1, and \( V_g^0 \) is the headspace volume.

If a certain volume \( V_s \) of concentrated solution with a known solute concentration of \( C_s \) is added into this system, the existing equilibrium will be disturbed and a new equilibration state will be established after a while. The amount of solute in the vapor phase under the new equilibration state can be expressed as:

\[
\eta_2 = C_0 V_i^0 + C_s V_s - \alpha C_2 V_i^0 = C_g^2 V_g^0,
\]

where we assume that the total volume of the solution keeps the same as the volume of the concentrated solution added is negligible compared with the initial volume of the solution, i.e., \( V_i^0 \gg V_s \).

From Eqns. (1) and (2), we can obtain the concentrations of the solute in the liquid phase under the two equilibrium states,

\[
\frac{C_1}{C_g} = \frac{C_0 V_i^0 - C_g^1 V_g^0}{\alpha V_i^0 C_g^1}, \quad \text{and}
\]

\[
\frac{C_2}{C_g^2} = \frac{C_0 V_i^0 + C_s V_s - C_g^2 V_g^0}{\alpha V_i^0 C_g^2}.
\]

By assuming that the solute is infinite dilution in both vials, we can use the Henry’s Law to connect Eqns. (3) and (4) as follows,

\[
H_c = \frac{C_g^1}{C_1} = \frac{C_g^2}{C_2}.
\]
Then, the initial solute concentration in the sample solution can be calculated from Eqns. (3)-(5) as,

\[
C_0 = \frac{C_s V_s}{(C_g / C_i/g - 1)V_i^0},
\]

where, the ratio of the solute concentration in the vapor \(C_g^2/C_i^g\) is proportional to the ratio \(r_A\) of the peak areas \(A_1\) and \(A_2\) of the solute detected from the two HSGC measurements. We can rewrite Eqn. (6) as,

\[
C_0 = \frac{C_s V_s}{(A_2 / A_i - 1)V_i^0} = \frac{C_s V_s}{(r_A - 1)V_i^0}.
\]

Eqn. (7) can be used to determine the VOC contents in various mill streams. The advantage of the present method is that it does not require calibration.

**Determination of VOC Henry’s Constants in Kraft Mill Streams**

The VOC’s in mill streams are small quantities and can be treated under infinite dilution. Therefore, the Henry’s law in Eqn. (5) best describes the VLE partitioning of VOC’s in Kraft mill streams. Determination of Henry’s constants is the key to understanding the thermodynamic VLE behavior of VOC’s in mill streams.

The indirect GSGC method we developed uses two sample vials both filled with the same sample solution but with a significant variation in volume as schematically shown in Fig. 2. We conducted a headspace analysis of each sample after a phase equilibrium was established within each vial. The solute of the two systems has the same VLE Henry’s constant as the two systems are identical, which can be used to connect the two independent headspace measurements to determine the solute concentration in the original sample. The derivation of the present method
is very simple. We can express the total moles \( M \) of the solute under equilibrium in the two vials using Eqns. (1) and (5),

\[
M_1 = C^0_i V^1_i = C^1_i V^1_i + C^1_g V^1_g = C^1_i \left[ \frac{V^1_i}{H_c} + V^1_g \right],
\]

\[
M_2 = C^0_i V^2_i = C^2_i V^2_i + C^2_g V^2_g = C^2_i \left[ \frac{V^2_i}{H_c} + V^2_g \right],
\]

(8) (9)

where \( C_g \) is the concentration of solute in the vapor phase, and \( V_g \) is the vapor volume in the vial.

The dimensionless Henry’s constant \( H_c \) can be derived from Eqns. (8) and (9),

\[
H_c = \frac{V^1_i \left( \frac{1}{C^1_i} \right)}{C^1_i / C^2_i (V_i - V^1_i) - V^1_i / V^2_i (V_i - V^2_i)}. \]

(10)

The solute concentration in the vapor phase \( C_g \) is proportional to the peak area from GC measurement. Thus, we have

\[
\frac{C^1_i}{C^2_i} = \frac{A_1}{A_2}. \]

(11)

Substituting Eqn. (11) into (10), the dimensionless Henry’s constant \( H_c \) can be determined

\[
H_c = \frac{V^1_i \left( \frac{1}{A_1 / A_2} \right)}{A_1 / A_2 (V^1_i - V^1_i) - V^1_i / V^2_i (V^1_i - V^2_i)} = \frac{V^1_i (1 - r)}{r(V^1_i - V^1_i) - x(V^1_i - V^2_i)},
\]

(12)

where \( r = A_1 / A_2 \), and \( x = V^1_i / V^2_i \).

The approach that we took to derive the present indirect HSGC method is very similar to that of the Equilibrium Partitioning in Closed Systems (EPICS) method developed by Lincoff and Gossett [12]. However, the present method differs from the EPICS method significantly. It overcomes all the shortcomings of the EPICS method and has the following advantages: (1) it
does not require that one know the solute concentration to determine the VLE partitioning coefficient of the solution, which has significant importance for any industrial, environmental, and practical application; (2) it does not need to assume that the solute is under infinite dilution; therefore, the method is not only applicable to measure the Henry’s constant, but also to measure the partitioning coefficient \( K \) of a solute in any solution; and (3) it has high precision even for determining a very small Henry’s constant \( (H_c<0.1) \).

**EXPERIMENTAL**

**Chemicals**

We used methanol, methyl ethyl ketone (MEK), and acetone to mix with deionized water to make standard solutions of methanol-water, MEK-water, and acetone-water to validate the present methods.

We conducted measurements of VOC contents and VLE partitioning in various mill streams from four separate Kraft mills (Mills A, B, C, and D) to demonstrate the applicability of the present methods.

**Apparatus and Operation**

All measurements were carried out using an HP-7694 Automatic Headspace Sampler and Model HP-6890 capillary gas chromatography (Hewlett-Packard). A detailed description and the basic operation principles of the headspace sampler can be found in Dhasmana et al. [13]. GC conditions: HP-5 capillary column at 30°C; carrier gas helium flow (He): 3.8 mL/min. A flame ionization detector (FID) was employed with hydrogen and air flows of 35 and 400 mL/min, respectively. Headspace operating conditions: 25 minutes gentle shaking for
equilibration of the sample, vial pressurization time: 0.2 min, sample loop fill time: 1.0 min., and loop equilibration time: 0.05 min.

**Temperature of the Headspace Sampler**

For VOC content measurements, we set the temperature of the headspace sampler at 70°C to avoid water vaporization and obtain a good sensitivity as sufficient methanol will be present in the vapor phase at this temperature. The temperature was varied from 45-80°C for vapor-liquid partitioning measurements, close to the range of operating temperatures of most mill streams.

**RESULTS AND DISCUSSION**

**VOC Content Measurements**

*Technique Validation*

The experimental technique is validated using a set of standard VOC-water (methanol-water, MEK-water, and acetone-water) solutions with known concentrations. The present method measures the VOC concentration of the standard solutions according to Eqn. (7). The ranges of the concentrations of these three standard solutions are 100-2000, 10-100, and 1-10 ppm, respectively. The combination of these three concentration ranges covers trace species concentration over three orders of magnitude within the infinite dilution assumption limit. The comparison between the standard and the measured data is excellent. A perfect correlation between the standard and the measured is shown in Fig. 3. The repeatability of the method was demonstrated by using a standard methanol-water solution (methanol concentration = 800 ppm). A relative standard deviation of measured liquid methanol content is about 2.0% for the five measurements conducted, indicating that the repeatability of the technique is excellent.
Measurements of the VOC content in black liquor samples is very difficult because it has a complex composition such as dissolved solids and it is corrosive. We were able to separate various volatile species in black liquor using the GC system and the conditions stated previously [13]. We measured methanol contents in four black liquor samples from Mills A and B using the present method. Our data agree with the results obtained using the NCASI method [3] as shown in Table 1, indicating the applicability of the present method.

Measurements in Various Mill Streams

We measured methanol and MEK contents in various Kraft mill streams from Mill C using the present method. The results are shown in Table II. Mill C is a unbleached Kraft paper mill. For this particular mill, the data indicate: (1) the weak wash stream in the recovery cycle does not contain methanol; (2) the shower water and filtrate streams in the washers contain a significant amount of methanol; (3) the blow tank condensate stream from the digester also has a high content of methanol as indicated by the measurement of the sample from the hot water tank; (4) the white water from the paper-machine head tank for the present unbleached mill contains some methanol; (5) weak black liquor has a significant amount of methanol; and (6) MEK concentrations in various streams are in the order of a several hundred of ppb, and they do not have a direct correlation with the concentrations of methanol. The measured methanol contents in various streams are reasonable with practical knowledge. Similar conclusions can be drawn from the measurements of VOC concentrations of various streams in another unbleached Mill D as shown in Table III. The absolute concentrations of VOC’s in mill streams depend on various factors such as water dilution, mill operating conditions, and VOC formation during pulping that will be reported in the future.
**Henry's Constant Measurements**

**Technique Validation**

We found from mathematical precision analysis [11] that the present method can be very accurate by properly choosing the two key experimental parameters, i.e., the solution volume ratio \(x\) and the volume of the sample \(V_i^1\) or \(V_i^2\). We applied the present method to measure the methanol Henry’s constant in a methanol-water mixture. The Henry’s constant of methanol in water under a temperature range of 45-80°C is very small (<0.005); therefore, it is a good precision test of the present method. The data obtained using the present indirect HSGC method show excellent agreement with those in the literature [14-18] as shown in Fig. 4. A linear regression analysis shows that the logarithm of all the data fit to a straight line with the inverse of temperature very well. The linear relationship agrees with thermodynamic theory, i.e., the Henry’s constant is related to the partial molar excess enthalpy, which is a weak function of temperature. The data demonstrate the validity and the accuracy of the present method.

**Measurements in Black Liquors**

We applied the present method to measure Henry’s constant of methanol in black liquor. Both softwood and hardwood black liquor samples from Mill B were used in this study. Fig. 5 shows the effect of temperature on the methanol Henry’s constant in black liquors along with the data obtained in the methanol-water mixture. The results indicate that the logarithm of Henry’s constant in the two black liquor samples decreases linearly with the inverse of temperature. It appears that the slopes of the three sets of data presented are the same; the differences are within the error margin. However, the variation in the measured Henry’s constant among these three types of samples is very significant. It is obvious that there is a significant variation in the
composition, ionic strength, solid contents, etc., among these samples, which may cause the large variation in the Henry’s constant. We are conducting a detailed study to understand the effect of various parameters on the Henry’s constant, which will be reported in Part II of this study.

CONCLUSIONS

The present study reported on the development of indirect methods for measuring VOC concentration and vapor-liquid phase equilibrium partitioning coefficients in mill streams using a commercial headspace gas chromatography system. The methods are rapid, automated, and accurate, and do not require calibration and modification of the sample matrix. The method can also be applied to various industrial and environmental streams. Preliminary measurements of VOC content and Henry’s constant of methanol in Kraft mill streams using the methods developed were conducted. Significant variation in the measured data was observed, indicating the complicated nature of the behaviors of VOC in Kraft mill streams.

ACKNOWLEDGEMENT

This research was supported by the United States Department of Energy (Grant No. DE-FC07-96ID13438) and the State of Georgia (Grant No. PP97-EN5).
REFERENCES


**List of Figures**

Fig. 1. Comparison between the measured and the known VOC concentrations in standard VOC-water solutions.

Fig. 2. Schematic diagram describing the present indirect HSGC method for VOC content measurements.

Fig. 3. Schematic diagram describing the present indirect HSGC method for VLE partitioning Henry’s constant measurements.

Fig. 4. Temperature effect on methanol Henry’s constant and a comparison with literature data.

Fig. 5. Measured methanol Henry’s constant in two black liquor samples.

**List of Tables**

Table I. Comparisons of measured liquid methanol content in four black liquors using the NCASI method and the present method.

Table II. Methanol and MEK contents measured in various streams from Mill C.

Table III. VOC contents measured in various streams from Mill D.
Fig. 1

Sample from Mill
C₀ = ?

Room T

\[
C₀ = \frac{C_s V_s}{\left(\frac{C_g^2}{C_g^1} - 1\right)V_l^0}
\]

Vial = 20 mL
Room T
Vₙ = 10 μL
V_l^0 = 10 mL

Heat
T = 70°C

\[
H_c = \frac{C_g^2}{C_g^1}
\]
Fig. 2

\[ H_c = \frac{V_i^1 (1 - C_i / C_g^1)}{C_g^1 / C_g^0 (V_i - V_i^1) - V_i^1 / V_i^2 (V_i - V_i^2)} \]

\[ V_i = 20 \text{ mL} \]

\[ \text{Room T} \]

\[ \text{Heat} \]

\[ T = \text{Constant} \]

\[ H_c = \]

\[ C_g^1 \]

\[ C_1 \]

\[ C_g^2 \]

\[ C_2 \]
Fig. 3

1000 m Methanol
C\textsubscript{\textregistered}, MEK, & Acetone

Standard Concentration (ppm)

Measured Concentration (ppm)

- Methanol
- MEK
- Acetone
Fig. 4

![Graph showing the relationship between $H_c$ and $1/T(K)$ with data points and a least square fitted line. The equation for the fitted line is $\log(H_c) = 3.49567 - 2147.23/T$.]

- Present data
- Hofstee et al., 1960 [14]
- Pividal et al., 1992 [15]
- Dallas, 1993 [16]
- Kooner et al., 1980 [17]
- Lebert and Richon, 1984 [18]
Table I

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>Solids Content (%)</th>
<th>Methanol Concentration (ppm)</th>
<th>NCASI Method</th>
<th>Present Method</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Softwood, Mill A</td>
<td>15.2</td>
<td></td>
<td>775</td>
<td>736</td>
<td>5.0</td>
</tr>
<tr>
<td>Hardwood, Mill A</td>
<td>17.1</td>
<td></td>
<td>961</td>
<td>906</td>
<td>5.7</td>
</tr>
<tr>
<td>Softwood, Mill B</td>
<td>11.5</td>
<td></td>
<td>434</td>
<td>419</td>
<td>3.5</td>
</tr>
<tr>
<td>Hardwood, Mill B</td>
<td>10.8</td>
<td></td>
<td>527</td>
<td>560</td>
<td>-6.3</td>
</tr>
</tbody>
</table>

Table II

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Sample Location Description</th>
<th>Methanol (ppm)</th>
<th>MEK (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>weak wash liquor from recovery cycle</td>
<td>&lt;1</td>
<td>74.5</td>
</tr>
<tr>
<td>2</td>
<td>white water from paper-machine head tank</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>pulp wash shower water first stage digester (D1)</td>
<td>277</td>
<td>165</td>
</tr>
<tr>
<td>4</td>
<td>filtrated stream from first washing stage (D1)</td>
<td>251</td>
<td>433</td>
</tr>
<tr>
<td>5</td>
<td>filtrated stream from second washing stage (D1)</td>
<td>238</td>
<td>316</td>
</tr>
<tr>
<td>6</td>
<td>filtrated stream from first washing stage (D2)</td>
<td>201</td>
<td>583</td>
</tr>
<tr>
<td>7</td>
<td>filtrated stream from second washing stage (D2)</td>
<td>172</td>
<td>481</td>
</tr>
<tr>
<td>8</td>
<td>condensed stream of blow tank steam in hot water tank</td>
<td>315</td>
<td>251</td>
</tr>
<tr>
<td>9</td>
<td>weak black liquor to evaporator</td>
<td>272</td>
<td>307</td>
</tr>
<tr>
<td>Sample Location Description</td>
<td>Label</td>
<td>MeOH (ppm)</td>
<td>Acetone (ppb)</td>
</tr>
<tr>
<td>-----------------------------------------------------------</td>
<td>------------------------</td>
<td>------------</td>
<td>---------------</td>
</tr>
<tr>
<td>1st stage showers, 2nd stage filtrate</td>
<td>No. 1 Washer</td>
<td>209.5</td>
<td>494</td>
</tr>
<tr>
<td></td>
<td>No. 2 Washer</td>
<td>275.0</td>
<td>484</td>
</tr>
<tr>
<td>2nd stage showers, 1st stage filtrate</td>
<td>No. 1 Washer</td>
<td>149.8</td>
<td>980</td>
</tr>
<tr>
<td></td>
<td>No. 2 Washer</td>
<td>312.7</td>
<td>852</td>
</tr>
<tr>
<td>3rd stage showers</td>
<td>No. 1 Washer</td>
<td>122.6</td>
<td>683</td>
</tr>
<tr>
<td></td>
<td>No. 2 Washer</td>
<td>203.8</td>
<td>715</td>
</tr>
<tr>
<td>side combined condensate (blow recovery)</td>
<td>No. 1 Washer</td>
<td>178.6</td>
<td>1327</td>
</tr>
<tr>
<td></td>
<td>No. 2 Washer</td>
<td>382.6</td>
<td>1113</td>
</tr>
<tr>
<td>1st stage filtrate</td>
<td>No. 2 Washer</td>
<td>349.0</td>
<td>520</td>
</tr>
<tr>
<td>3rd stage filtrate</td>
<td>No. 1 Washer</td>
<td>332.2</td>
<td>930</td>
</tr>
<tr>
<td>combined weak black liquor to recovery</td>
<td>No. 2 (M24-0542)</td>
<td>292.4</td>
<td>670</td>
</tr>
<tr>
<td>evaporator seal tank condensate</td>
<td>No. 2 (24-0529)</td>
<td>93.1</td>
<td>762</td>
</tr>
<tr>
<td>evaporator clean condensate</td>
<td>No. 3</td>
<td>2.0</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>No. 3 (24-0509)</td>
<td>1.7</td>
<td>-</td>
</tr>
<tr>
<td>evaporator</td>
<td>No. 2</td>
<td>27.1</td>
<td>-</td>
</tr>
<tr>
<td>evaporator seal tank</td>
<td>No. 1 (M24-0027)</td>
<td>3954.4</td>
<td>11</td>
</tr>
<tr>
<td>combined condensate of hotwell</td>
<td>No. 3</td>
<td>659.1</td>
<td>16067</td>
</tr>
<tr>
<td>paper-machine condensate</td>
<td>No. 1</td>
<td>3.3</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>No. 2 &amp; No. 3</td>
<td>3.5</td>
<td>-</td>
</tr>
<tr>
<td>top headbox</td>
<td>No. 1</td>
<td>57.4</td>
<td>323</td>
</tr>
<tr>
<td></td>
<td>No. 2</td>
<td>55.3</td>
<td>260</td>
</tr>
<tr>
<td>base headbox</td>
<td>No. 1</td>
<td>88.8</td>
<td>433</td>
</tr>
<tr>
<td></td>
<td>No. 2</td>
<td>64.9</td>
<td>315</td>
</tr>
<tr>
<td>headbox</td>
<td>No. 3</td>
<td>46.8</td>
<td>-</td>
</tr>
<tr>
<td>wire pit</td>
<td>No. 1</td>
<td>86.5</td>
<td>375</td>
</tr>
<tr>
<td></td>
<td>No. 2</td>
<td>91.8</td>
<td>508</td>
</tr>
<tr>
<td></td>
<td>No. 3</td>
<td>90.9</td>
<td>-</td>
</tr>
<tr>
<td>water reclaim sump</td>
<td>No. 1</td>
<td>13.0</td>
<td>192</td>
</tr>
<tr>
<td>vacuum dump</td>
<td>No. 2</td>
<td>20.6</td>
<td>-</td>
</tr>
<tr>
<td>side hill screen drain off</td>
<td>No. 3</td>
<td>65.7</td>
<td>-</td>
</tr>
</tbody>
</table>