Monitoring the state of flowing water in purification and water supply systems

F A Isakov¹, V I Svyatkina¹ and M V Diuldin¹, ²

¹Peter the Great Saint Petersburg Polytechnic University, Saint Petersburg, 195251, Russia
²All Russian Research Institute of Phytopathology, Moscow Region 143050, Russia

e-mail: Ifa-spb@yandex.ru

Abstract. The article substantiates the need to control water at various stages of its purification before consumption. Several stages of water purification in the city of St. Petersburg are considered. The advantages and disadvantages of the used water control system are noted. Various options for monitoring the state of water in the pipeline between cleaning cycles are considered. The advantages of using a refractometer for monitoring the purity (quality) of water are shown.

1. Introduction

In the modern world, there is a constant tendency for the deterioration of the ecological situation [1-10]. This is especially pronounced near large cities and in areas with a high population density [11-18]. In these regions, various disasters occur, there is a lack of water and others [12-16, 19-23]. River and lake formations in these areas are most heavily polluted, both by industrial waste and by discharges of water from treatment facilities of various settlements and agricultural enterprises [12, 13, 19, 24-27], in which the treatment is carried out in an incomplete cycle.

The city of St. Petersburg (Russian Federation) is an exception to this rule. There is no shortage of water in the city. But the water quality in the Neva River and Lake Ladoga is constantly deteriorating. Studies of the water area of Lake Ladoga by various methods [28-42] have shown this well. The Neva River flows out of Lake Ladoga.

The state unitary enterprise Vodokanal of Saint Petersburg, which has been operating since 1858, is responsible for the quality of tap water in the city of St. Petersburg. The responsibilities of this organization include the preparation of drinking water, wastewater treatment and disposal of their sludge. The main source of water supply for the city is the Neva River. 98% of the water is taken from it, which is then processed at 11 city waterworks. The remaining 2% is groundwater used in the suburban area. The Neva River is also an acceptor, accepting wastes from St. Petersburg enterprises and wastes that enter Lake Ladoga from other rivers. Both small businesses and residents dump waste into these rivers (Fig. 1).

Therefore, before the water enters the user's faucet, it goes through several stages of cleaning:

• ammonization (purification of raw water) using safe ammonium sulfate instead of ammonia solutions;
• disinfection using sodium hypochlorite instead of liquid chlorine (used until 2009);
• treatment with ultraviolet light, which guarantees epidemiological safety;
• coagulation with aluminum sulfate;
• flocculation (removal of the smallest impurities) with a cationic flocculant;
• settling and filtration through sand loading;
• use of powdered activated carbon to remove oil products and odors.

Figure 1. Waste discharge into small rivers of the Leningrad region

At each stage, water is controlled by specialized laboratories. All this requires specialists from different scientific fields. In conditions of increasing water consumption and time for its purification, automatic systems for monitoring the state of flowing water in the pipeline are required. This will automate production and reduce cleaning costs or introduce an additional cycle, as time is saved. Therefore, the development of various automated control systems using various instruments is extremely important. Instead, you can install a flow refractometer into the system, which will measure the refractive index of the sample flowing through the pipe, in our case, water. If the amount of harmful impurities exceeds the specified rate at a certain stage of cleaning, then the refractive index will change, the device will record this and transmit the necessary information to the system. Thus the water is monitored in real time.

2. Research methodology and instruments

Currently, not many devices have been developed that can monitor the state of the current fluid flow [21, 22, 43–47]. One of them is a flow-through refractometer. This device measures the refractive index \( n \) of a flowing medium (water). If the amount of harmful impurities exceeds the specified rate at a certain stage of cleaning, then the value of \( n \) (refractive index) will change, the device will record this. The electronics will transmit the necessary information to the monitoring and control system. And a command will be given to perform an operation in the technological process, which will eliminate this drawback in the operation of the cleaning system.

Preliminary studies have shown that the change in the refractive index of the studied medium must be controlled up to the fifth decimal place when the temperature changes within 20 K. Before implementing control in automatic mode, it is necessary to understand what range of measurements of the refractive index corresponds to the norm at various stages of cleaning and in what range it can change. This will allow you to adjust the flow refractometers for different measurement ranges and eliminate errors when monitoring the water condition.

The refractive index data is also entered into the control system base for general management and control of the entire cleaning process.
3. Results of experimental studies and their discussion

The performance results of in-line refractometers have been tested in various water conditions. This is distilled water, water from a drinking cooler and from a tap, which is located in the house of residents. To determine the measurement error, 10 measurements of the refractive index were performed at different temperatures. The temperature range was chosen from 283 to 303 K. This is the most standard temperature range for water purification, transportation and a number of consumptions. For a more convenient understanding of the results of water studies, the n values were placed in tables.

**Table 1. Refractive index versus distilled water temperature.**

| Temperature, °K | 1st dim. | 2nd dim. | 3rd dim. | 4th dim. | 5th dim. | 6th dim. | 7th dim. | 8th dim. | 9th dim. | 10th dim. | Average |
|----------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|-----------|---------|
| 283,15         | 1.33373  | 1.33368  | 1.33369  | 1.33368  | 1.33369  | 1.33369  | 1.33368  | 1.33368  | 1.33368  | 1.33368   | 1.333689 |
| 284,15         | 1.33363  | 1.33362  | 1.33362  | 1.33362  | 1.33362  | 1.33362  | 1.33362  | 1.33362  | 1.33362  | 1.33362   | 1.333621 |
| 285,15         | 1.33356  | 1.33356  | 1.33357  | 1.33357  | 1.33357  | 1.33357  | 1.33356  | 1.33357  | 1.33357  | 1.33357   | 1.333566 |
| 286,15         | 1.33347  | 1.33345  | 1.33345  | 1.33344  | 1.33345  | 1.33345  | 1.33345  | 1.33345  | 1.33345  | 1.33345   | 1.333496 |
| 287,15         | 1.33343  | 1.33343  | 1.33343  | 1.33343  | 1.33343  | 1.33343  | 1.33343  | 1.33343  | 1.33343  | 1.33343   | 1.33343  |
| 288,15         | 1.33336  | 1.33336  | 1.33336  | 1.33336  | 1.33336  | 1.33336  | 1.33336  | 1.33336  | 1.33336  | 1.33336   | 1.33339  |
| 289,15         | 1.33328  | 1.33328  | 1.33328  | 1.33328  | 1.33328  | 1.33328  | 1.33328  | 1.33328  | 1.33328  | 1.33328   | 1.33328  |
| 290,15         | 1.33321  | 1.33321  | 1.33321  | 1.33321  | 1.33321  | 1.33321  | 1.33321  | 1.33321  | 1.33321  | 1.33321   | 1.333209 |
| 291,15         | 1.33312  | 1.33312  | 1.33312  | 1.33312  | 1.33312  | 1.33312  | 1.33312  | 1.33312  | 1.33312  | 1.33312   | 1.333119 |
| 292,15         | 1.33303  | 1.33303  | 1.33303  | 1.33303  | 1.33303  | 1.33303  | 1.33303  | 1.33303  | 1.33303  | 1.33303   | 1.33303  |
| 293,15         | 1.33294  | 1.33294  | 1.33294  | 1.33294  | 1.33294  | 1.33294  | 1.33294  | 1.33294  | 1.33294  | 1.33294   | 1.33294  |
| 294,15         | 1.33285  | 1.33286  | 1.33286  | 1.33285  | 1.33285  | 1.33285  | 1.33285  | 1.33285  | 1.33285  | 1.33285   | 1.332853 |
| 295,15         | 1.33276  | 1.33276  | 1.33277  | 1.33276  | 1.33276  | 1.33276  | 1.33276  | 1.33276  | 1.33276  | 1.33276   | 1.332763 |
| 296,15         | 1.33267  | 1.33266  | 1.33266  | 1.33267  | 1.33267  | 1.33266  | 1.33266  | 1.33266  | 1.33266  | 1.33266   | 1.332663 |
| 297,15         | 1.33256  | 1.33256  | 1.33256  | 1.33256  | 1.33256  | 1.33256  | 1.33256  | 1.33256  | 1.33256  | 1.33256   | 1.33256  |
| 298,15         | 1.33247  | 1.33247  | 1.33247  | 1.33247  | 1.33247  | 1.33247  | 1.33247  | 1.33247  | 1.33247  | 1.33247   | 1.33247  |
| 299,15         | 1.33236  | 1.33236  | 1.33235  | 1.33236  | 1.33236  | 1.33236  | 1.33236  | 1.33236  | 1.33236  | 1.33236   | 1.332353 |
| 300,15         | 1.33224  | 1.33224  | 1.33224  | 1.33224  | 1.33224  | 1.33224  | 1.33224  | 1.33224  | 1.33224  | 1.33224   | 1.33224  |
| 301,15         | 1.33212  | 1.33213  | 1.33213  | 1.33213  | 1.33213  | 1.33213  | 1.33213  | 1.33213  | 1.33213  | 1.33213   | 1.332128 |
| 302,15         | 1.33201  | 1.33202  | 1.33202  | 1.33202  | 1.33202  | 1.33202  | 1.33202  | 1.33202  | 1.33202  | 1.33202   | 1.332019 |
| 303,15         | 1.33189  | 1.33189  | 1.33189  | 1.33189  | 1.33189  | 1.33189  | 1.33189  | 1.33189  | 1.33189  | 1.33189   | 1.331894 |
Table 2 The dependence of the refractive index on the temperature of the water from the cooler.

| Temperature, °K | 1st dim. | 2nd dim. | 3rd dim. | 4th dim. | 5th dim. | 6th dim. | 7th dim. | 8th dim. | 9th dim. | 10th dim. | Average |
|-----------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|-----------|---------|
| 283,15          | 1.33372  | 1.33372  | 1.33372  | 1.33372  | 1.33372  | 1.33372  | 1.33372  | 1.33372  | 1.33372  | 1.33372  | 1.33372 |
| 284,15          | 1.33366  | 1.33366  | 1.33366  | 1.33366  | 1.33366  | 1.33366  | 1.33366  | 1.33366  | 1.33366  | 1.33366  | 1.33366 |
| 285,15          | 1.3336   | 1.3336   | 1.3336   | 1.3336   | 1.3336   | 1.3336   | 1.3336   | 1.3336   | 1.3336   | 1.3336   | 1.3336   |
| 286,15          | 1.33353  | 1.33354  | 1.33354  | 1.33354  | 1.33354  | 1.33354  | 1.33354  | 1.33354  | 1.33354  | 1.33354  | 1.33354 |
| 287,15          | 1.33345  | 1.33346  | 1.33346  | 1.33346  | 1.33346  | 1.33346  | 1.33346  | 1.33346  | 1.33346  | 1.33346  | 1.33346 |
| 288,15          | 1.33339  | 1.33339  | 1.33338  | 1.33338  | 1.33338  | 1.33338  | 1.33338  | 1.33338  | 1.33338  | 1.33338  | 1.33338 |
| 289,15          | 1.3333   | 1.33331  | 1.33331  | 1.33331  | 1.33331  | 1.33331  | 1.33331  | 1.33331  | 1.33331  | 1.33331  | 1.33331 |
| 290,15          | 1.33322  | 1.33322  | 1.33322  | 1.33322  | 1.33322  | 1.33322  | 1.33322  | 1.33322  | 1.33322  | 1.33322  | 1.33322 |
| 291,15          | 1.33315  | 1.33315  | 1.33315  | 1.33315  | 1.33315  | 1.33315  | 1.33315  | 1.33315  | 1.33315  | 1.33315  | 1.33315 |
| 292,15          | 1.33305  | 1.33305  | 1.33305  | 1.33305  | 1.33305  | 1.33305  | 1.33305  | 1.33305  | 1.33305  | 1.33305  | 1.33305 |
| 293,15          | 1.33296  | 1.33296  | 1.33296  | 1.33296  | 1.33296  | 1.33296  | 1.33296  | 1.33296  | 1.33296  | 1.33296  | 1.33296 |
| 294,15          | 1.33286  | 1.33286  | 1.33286  | 1.33286  | 1.33286  | 1.33286  | 1.33286  | 1.33286  | 1.33286  | 1.33286  | 1.33286 |
| 295,15          | 1.33279  | 1.33279  | 1.33279  | 1.33279  | 1.33279  | 1.33279  | 1.33279  | 1.33279  | 1.33279  | 1.33279  | 1.33279 |
| 296,15          | 1.33269  | 1.3327   | 1.3327   | 1.33269  | 1.33269  | 1.33269  | 1.33269  | 1.33269  | 1.33269  | 1.33269  | 1.33269 |
| 297,15          | 1.33259  | 1.33259  | 1.33259  | 1.33259  | 1.33259  | 1.33259  | 1.33259  | 1.33259  | 1.33259  | 1.33259  | 1.33259 |
| 298,15          | 1.33248  | 1.33248  | 1.33248  | 1.33248  | 1.33248  | 1.33248  | 1.33248  | 1.33248  | 1.33248  | 1.33248  | 1.33248 |
| 299,15          | 1.33238  | 1.33238  | 1.33238  | 1.33238  | 1.33238  | 1.33238  | 1.33238  | 1.33238  | 1.33238  | 1.33238  | 1.33238 |
| 300,15          | 1.33227  | 1.33227  | 1.33227  | 1.33227  | 1.33227  | 1.33227  | 1.33227  | 1.33227  | 1.33227  | 1.33227  | 1.33227 |
| 301,15          | 1.33215  | 1.33215  | 1.33215  | 1.33215  | 1.33215  | 1.33215  | 1.33215  | 1.33215  | 1.33215  | 1.33215  | 1.33215 |
| 302,15          | 1.33203  | 1.33203  | 1.33203  | 1.33203  | 1.33203  | 1.33203  | 1.33203  | 1.33203  | 1.33203  | 1.33203  | 1.33203 |
| 303,15          | 1.33192  | 1.33193  | 1.33193  | 1.33193  | 1.33193  | 1.33193  | 1.33193  | 1.33193  | 1.33193  | 1.33193  | 1.33192 |
Table 3. The dependence of the refractive index on the temperature of tap water from the tap.

| Temperature, °K | 1st dim. | 2nd dim. | 3rd dim. | 4th dim. | 5th dim. | 6th dim. | 7th dim. | 8th dim. | 9th dim. | 10th dim. | Average |
|----------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|----------|---------|
| 283.15         | 1.3337  | 1.3337  | 1.3337  | 1.3337  | 1.3337  | 1.3337  | 1.3337  | 1.3337  | 1.3337  | 1.3337   | 1.3337  |
| 284.15         | 1.3336  | 1.3336  | 1.3336  | 1.3336  | 1.3336  | 1.3336  | 1.3336  | 1.3336  | 1.3336  | 1.3336   | 1.3336  |
| 285.15         | 1.3335  | 1.3335  | 1.3336  | 1.3336  | 1.3336  | 1.3336  | 1.3336  | 1.3336  | 1.3336  | 1.3336   | 1.3336  |
| 286.15         | 1.3335  | 1.3335  | 1.3335  | 1.3335  | 1.3335  | 1.3335  | 1.3335  | 1.3335  | 1.3335  | 1.3335   | 1.3335  |
| 287.15         | 1.3345  | 1.3345  | 1.3345  | 1.3345  | 1.3345  | 1.3345  | 1.3345  | 1.3345  | 1.3345  | 1.3345   | 1.3345  |
| 288.15         | 1.3337  | 1.3338  | 1.3338  | 1.3338  | 1.3338  | 1.3338  | 1.3338  | 1.3338  | 1.3338  | 1.3338   | 1.3338  |
| 289.15         | 1.3333  | 1.3333  | 1.3333  | 1.3333  | 1.3333  | 1.3333  | 1.3333  | 1.3333  | 1.3333  | 1.3333   | 1.3333  |
| 290.15         | 1.3322  | 1.3322  | 1.3322  | 1.3322  | 1.3322  | 1.3322  | 1.3322  | 1.3322  | 1.3322  | 1.3322   | 1.3322  |
| 291.15         | 1.3311  | 1.3315  | 1.3315  | 1.3315  | 1.3315  | 1.3315  | 1.3315  | 1.3315  | 1.3315  | 1.3315   | 1.3315  |
| 292.15         | 1.3305  | 1.3305  | 1.3305  | 1.3305  | 1.3305  | 1.3305  | 1.3305  | 1.3305  | 1.3305  | 1.3305   | 1.3305  |
| 293.15         | 1.3293  | 1.3296  | 1.3296  | 1.3296  | 1.3296  | 1.3296  | 1.3296  | 1.3296  | 1.3296  | 1.3296   | 1.3296  |
| 294.15         | 1.3289  | 1.3289  | 1.3289  | 1.3289  | 1.3289  | 1.3289  | 1.3289  | 1.3289  | 1.3289  | 1.3289   | 1.3289  |
| 295.15         | 1.3279  | 1.3279  | 1.3279  | 1.3279  | 1.3279  | 1.3279  | 1.3279  | 1.3279  | 1.3279  | 1.3279   | 1.3279  |
| 296.15         | 1.3277  | 1.3277  | 1.3269  | 1.3269  | 1.3269  | 1.3269  | 1.3269  | 1.3269  | 1.3269  | 1.3269   | 1.3269  |
| 297.15         | 1.3258  | 1.3259  | 1.3259  | 1.3259  | 1.3259  | 1.3259  | 1.3259  | 1.3259  | 1.3259  | 1.3259   | 1.3259  |
| 298.15         | 1.3248  | 1.3248  | 1.3248  | 1.3248  | 1.3248  | 1.3248  | 1.3248  | 1.3248  | 1.3248  | 1.3248   | 1.3248  |
| 299.15         | 1.3238  | 1.3238  | 1.3238  | 1.3238  | 1.3238  | 1.3238  | 1.3238  | 1.3238  | 1.3238  | 1.3238   | 1.3238  |
| 300.15         | 1.3227  | 1.3227  | 1.3227  | 1.3227  | 1.3227  | 1.3227  | 1.3227  | 1.3227  | 1.3227  | 1.3227   | 1.3227  |
| 301.15         | 1.3215  | 1.3215  | 1.3215  | 1.3215  | 1.3215  | 1.3215  | 1.3215  | 1.3215  | 1.3215  | 1.3215   | 1.3215  |
| 302.15         | 1.3204  | 1.3204  | 1.3204  | 1.3204  | 1.3204  | 1.3204  | 1.3204  | 1.3204  | 1.3204  | 1.3204   | 1.3204  |
| 303.15         | 1.3193  | 1.3193  | 1.3193  | 1.3193  | 1.3193  | 1.3193  | 1.3193  | 1.3193  | 1.3193  | 1.3193   | 1.3193  |

Studies have shown that water is adequate and can be consumed. The measurement error n does not exceed 10^{-4}, which is sufficient to determine the quality of water.

4. Conclusion
Analysis of the results obtained shows that a flow-through refractometer can be successfully used to control water quality. Unlike other devices [43-47], the current flow rate does not significantly affect the measurement error n. Also, the measurements carried out do not introduce irreversible changes in the composition and physical structure of the medium under study.

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