COMPARING AND ANALYZING TWO KINDS OF METHODS TO OBTAIN THE WATER BACKSCATTERING COEFFICIENT OF OIL POLLUTION WATER

Ying'en Huang[1], Miaofen Huang[2*], Yang Zhuang[3], Zhonglin Wang[4], Zhen Sun[5], Zhongyong Sun[6], Xufeng Xing[7]

[1]Guangdong Ocean University, No. 1 Haida Road, Mazhang District, Zhanjiang 524088, China
Email: bao_zugong@126.com
[2*]Guangdong Ocean University, No. 1 Haida Road, Mazhang District, Zhanjiang 524088, China
Email: hmf808@163.com
[3]Guangdong Ocean University, No. 1 Haida Road, Mazhang District, Zhanjiang 524088, China
Email: zhuangyang_libra@qq.com
[4]Dalian Ocean University, No. 52 Heishijiao Road, Shahekou District, Dalian 116023, China
Email: wzllin@126.com
[5]Dalian Ocean University, No. 52 Heishijiao Road, Shahekou District, Dalian 116023, China,
Email: sz_0224@163.com
[6]Guangdong Ocean University, No. 1 Haida Road, Mazhang District, Zhanjiang 524088, China
Email: sun_idea@163.com
[7]Guangdong Ocean University, No. 1 Haida Road, Mazhang District, Zhanjiang 524088, China
Email: 13500752437@163.com

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ABSTRACT: Backscattering is the main information from water in ocean color RS field, backscattering coefficient b_b is important in application. Furthermore, there are oil particles adhering to the suspended sediment in water actually. Thus, this test, mixing quartz sand, pure water, oil-pollute water into different concentrations to simulate the water in field. Direct measurement of b_b can only measure on one specific angle on several wavelength channels. For example, the instrument, HydroScat-6(HS-6), with 6 wavelength channels, can measure on 140°. Measuring the strong absorption water, sigma correction is necessary. Additionally, if couldn't measure in field, bring samples back to laboratory, a large number of samples should be brought back, because of the large size of instrument, the lens locating below the instrument, and requiring the certain depth of samples. The methods below are different from the above. Use LISST-100X and Wyatt Dawn Heleos II (DAWN), Mie scattering model indirectly get b_b. One method is using Mie scattering model and other equations to calculate the Volume Scattering Function (VSF) and b_b. The other is based on the value of the VSF previously obtained, calibrating the voltage value of the sample which is measured using DAWN, and obtained calibration formulas. Without LISST-100X, using DAWN and calibration formulas calculates the value of VSF and b_b. According to the characteristics of these methods, the test is divided into three phases. Firstly, the particle refractive index of quartz sand is known, so samples with quartz sand are used to calibrate the voltage value. Secondly, use the iterative and t-test methods to estimate the refractive index of the particle in other samples. Finally, compare and analyze the results and propose the improvement.

1. INTRODUCTION

1.1 Sheets for Papers and Typing

The rapid development of offshore oil and gas industry, has become an important part of the national development strategy. In 2013, about $360 billion was invested to offshore oil and gas exploration and development globally. The area of the investment distribute mainly in Africa, North America and Latin America, where the deep sea exploration and development investment will be about $213 billion in 2014-2018 (Wang,2014). China is facing both opportunities and challenges of offshore oil and gas exploration and development, should learn lessons and experience from successful foreign of it. During the period of "11th five-year plan", "12th five-year plan ", carry out the "Study of Deepwater Drilling Riser Systems" and other national projects (Wang & Zhu, 2014). However, as the offshore oil exploration and exploitation, oil pollution has become one of the main pollution of the marine environment.

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*Corresponding author: hmf808@163.com

Preventing oil pollution which has been an important topic of marine pollution is divided into chronic and acute mainly (Huang 2014). The chronic, is the pollution due mainly to the natural underwater leakage, oily sewage from port and shipping, sewage of industrial and anthropogenic. And the acute, mostly because of the oil spill accidents. After the oil spill accident occur, the processes of volatilization, diffusion and drift will happen simultaneously (Ji, Ge & Liang 1995). Except the constituent of volatilization, the spill oil will exist in marine environment for a long time and extend rapidly. The pollution leads great harm to environment as three sides of ecological hazard, social harm and enterprise hazard (Li, Wang & Ha 2014). And physical treatment, chemical treatment and biological treatment are the main trend of treatment to control the spill oil (Huang, 2014).

As the characteristics of fast, flexible and high precision, RS has become an effective method for disaster monitoring and evaluation (Li, Liu & Hu 2000). It is worth considering that it how to effectively use ocean color RS to monitor and evaluate the pollution of oil spill. However, water in shore of China belongs to case II water, of which constituent is much more complicated than case I, causing the inversion algorithm of many ocean color satellite cannot be used directly (Ren & Zhao, 2002). As the important parameter of ocean color RS, b_b can be measured by using HS-6 or BB-9. To protect the instrument, it cannot be used in some conditions, such as high waves, which cause missing data. Thus, if the measure can be done after sampling, the missing could be avoided. But the big size of instrument and the requirement of depth of sample, a large volume of sample should be collected if use HS-6 or BB-9. In test, discuss two method which cost a little water about 200ml via using two instruments - LISST-100X and DAWN and a theory-Mie scatter model.

2. MEASUREMENT

2.1 Direct Method

HS-6, for example, the instrument with six independent channels which are sensitivity to different width range of optical wavelengths that usually set as 442, 488, 532, 589, 676, 852 nm according to 'Technical specification for marine optical investigation' results in a measurement centered on a scattering angle of 140°. In Figure 1 (b), the instrument of which size is shown with the frame is put lateral, while should be sloped on a small angle when putting into water, moved up and down in the water before measure to ensure that no air bubbles under the lens, and kept vertical during measurement. As is shown from Figure 1 (a), there is a sampling volume and a certain distance between sample and instrument, so the size of the tank must be enough for measuring when in the laboratory. After measuring, the data of strong absorption water must be Sigma calibrated (Song, 2008). And BB-9, with nine wavelength channels-412, 440, 488, 510, 532, 595, 660, 676 and 715nm and the size of 30.5cm long and 14.6cm wide results in a measurement centered on a scattering angle of 117°. It also requires a sampling volume. In this test, the requiring volume of sample is no more than 200ml which could not only greatly reduce the need of sample, but facilitate the laboratory measurements, if it is feasible.
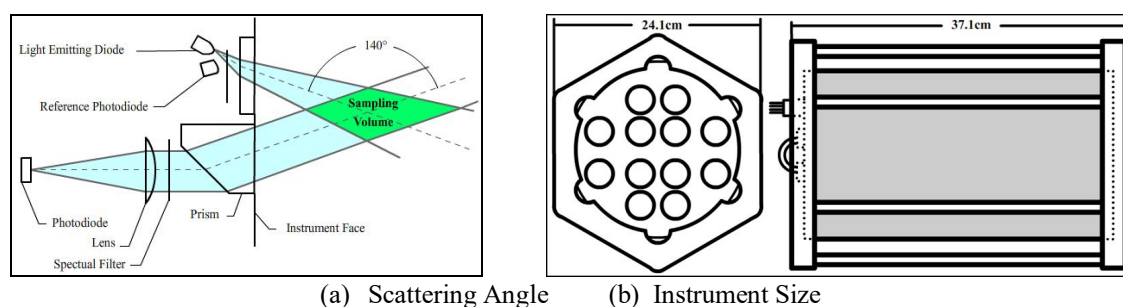

(a) Scattering Angle   (b) Instrument Size

Figure 1 schematic diagram of HS-6*
(* reference and adapt from HS-6 Manual 2008, Hydro-Optics, Biology, & Instrumentation Laboratories, Inc.)

2.2 Overview of Process

In this test, samples should be prepare by different content of quartz sand and oily sewage at first. And then: Firstly, calculating VSF - $\beta_L(\theta)$ by using LISST-100X to measure the concentration data of samples with quartz sand (QS samples), and using the Mie scattering model code with the quartz sand reflective index - $m_{QS} = 1.547$. Secondly, determining the calibration formula and coefficient via using Excel to fit $\beta_L(\theta)$ data and voltage value of QS samples measuring by DAWN. Thirdly, converting the voltage value of the samples with oily sewage (OS samples) and the samples with both quartz sand and oil-pollute water (QO samples) into VSF - $\beta_D(\theta)$. Fourthly, estimate the reflective index of the particles of OS samples - m_{OS} and QO samples - m_{QO} with iterative method and t test. Finally, compare

results of different methods after calculating b_b - b_{bL} and b_{bD} . The main processes are shown in Figure 2.

2.3 Method of Mie Scatter Model and LISST-100X

2.3.1 Samples Preparation: Samples of different concentration with particles are prepared by quartz sand, oily sewage and pure water. QS samples preparation procedure: weigh a certain weight of quartz sand by electronically analytical balance. Add the sand to a 5L conical flask with 5L pure water and shake up. OS samples preparation procedure: take a certain volume of oily sewage by glass measuring cylinder. Add the sewage to a 5L conical flask, add pure water to a total volume of 5L and shake up. QO samples preparation procedure: take a certain weight of the sand and volume of the sewage and pure water to a beaker, stir with a glass rod for 5 minutes, add to a 5L conical flask, and add pure water to a total volume of 5L and shake up. Among them, the oil concentration of the sewage collected from oilfield is 7.89 which measure by method of infrared spectrophotometry. The following Table 1 lists some samples and mixture proportioning:
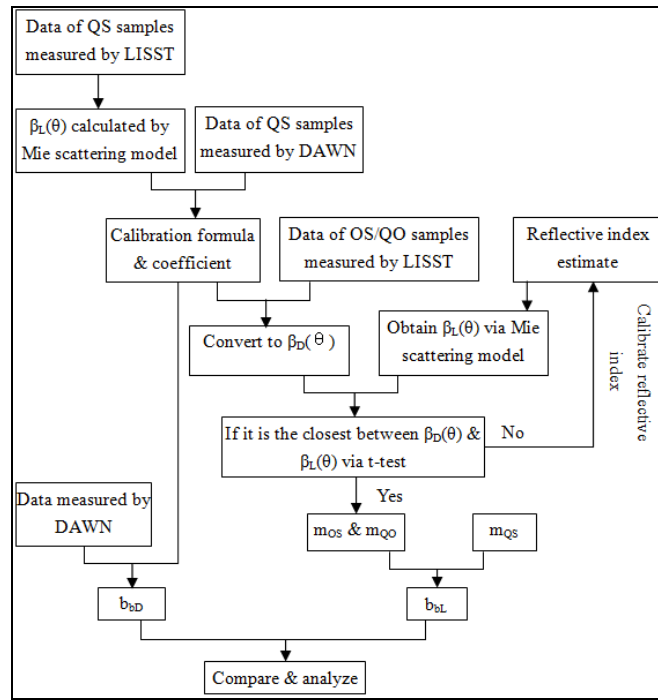

Figure 2. Main Processes of the Test

Table 1. Samples Concentration

QS samples concentration (mg/L)	OS samples concentration (ml/L)*	QO samples concentration (mg/L, ml/L)
5	50	5,50
10	100	10,100
20	200	20,200
30	300	30,300

* OS samples concentration means the volume of oil-pollute water that added to 1L pure water

2.3.2 Application of Mie Scattering Model and its Code: Light travels in straight line in vacuum or homogeneous medium. Actually, however, medium is often uneven with particles. In such medium reflection and scattering occurs during light traveling, and Mie scattering occurs when the wavelength of light and medium isotropic spherical particle diameter in the same order of magnitude. Suppose a beam of monochromatic light with the certain wavelength - λ that incidences to the particles with the certain diameter - D. Suppose two orthogonal component of the incident light - $E_\perp$ and $E_\parallel$, and two orthogonal component of the scattering light - $E_{\perp S}$ and $E_{\parallel S}$ of which the scattering angle is θ. Their relationship is represented as the following formula (Zhou, 2007):

$$\begin{pmatrix} E_{\perp S} \\ E_{\parallel S} \end{pmatrix} = \frac{eikr}{-ikr} \begin{pmatrix} S_1 & 0 \\ 0 & S_2 \end{pmatrix} \begin{pmatrix} E_\perp \\ E_\parallel \end{pmatrix}$$

(1)

Wherein, S_1 and S_2 are the scattering amplitude, their forms are shown following (Zhou, Cao & Li, 2007):

$$S_1(\theta) = \sum_{N=1}^{\infty} \frac{2N+1}{N(N+1)}(a_N \pi_N + b_N \tau_N) \tag{2}$$

$$S_2(\theta) = \sum_{N=1}^{\infty} \frac{2N+1}{N(N+1)}(a_N \tau_N + b_N \pi_N) \tag{3}$$

S1 and S2 will be convergent rapidly when $N > x$, so N_{max}, the maximum order of equation, can be used to replace the infinity (Wiscombe, 1979).

$$N_{max} = x + 4x^{1/3} + 2 \tag{4}$$

Then determine a_N, b_N, τ_N and π_N. a_N and b_N, the Mie scattering coefficient, are the functions which relate to relative refractive index - m and granularity - x represent as following Bessel-Ricatti function:

$$a_N = \frac{m\varphi_N(mx)\varphi'_N(x) - \varphi_N(x)\varphi'_N(mx)}{m\varphi_N(mx)\xi'_N(x) - \xi_N(x)\varphi'_N(mx)} \tag{5}$$

$$b_N = \frac{\varphi_N(mx)\varphi'_N(x) - m\varphi_N(x)\varphi'_N(mx)}{\varphi_N(mx)\xi'_N(x) - m\xi_N(x)\varphi'_N(mx)} \tag{6}$$

Wherein, $\varphi_N(x)$ and $\xi_N(x)$ conform the following formula (Zhou, Cao & Li, 2007):

$$\varphi_N(z) = \sqrt{\frac{z\pi}{2}}J_{N+1/2}(z) \tag{7}$$

$$\xi_N(z) = \sqrt{\frac{z\pi}{2}}(J_{N+1/2}(z) - iY_{N+1/2}(z)) \tag{8}$$

In the above formulas, J is the Bessel function of the first kind and Y is Bessel function of the second kind.

While τ_N and π_N, the angle coefficient, are the functions which relate to scattering angle - θ represent as following The first kind Lengendre polynomial function (Zhou,,2007):

$$\tau_N = \frac{dP_N^{(1)}(\cos\theta)}{d\theta} \tag{9}$$

$$\pi_N = \frac{P_N^{(1)}(\cos\theta)}{\sin\theta} \tag{10}$$

The above formulas can be replaced to the following recurrence relations (Shybanov,2002):

$$\begin{cases} \pi_0 = 0 \\ \pi_1 = 1 \\ \mu = \cos\theta \\ \pi_N = \frac{2N-1}{N-1}\mu\pi_{N-1} - \frac{N}{N-1}\pi_{N-2} \\ \tau_N = N\mu\pi_N - (N+1)\pi_{N-1} \end{cases} \tag{11}$$

And Mie intensity is a function relates the particle diameter - D, relative refractive index - m, and incidence light wavelength - λ. Therefore, after determining the parameters, in the test, the parameters of Mie scattering can be determined. And the calculating of m and x are represented as follows:

$$m = \frac{m_p}{m_m} \tag{12}$$

$$x = \frac{\pi D}{\lambda} \tag{13}$$

Here, m_p is the reflective index of the particle, m_m is the reflective index of the medium.

In the test, use the Matlab code that Christian Mätzler wrote to calculate the parameter of Mie scattering. Before running the code, the particle diameter, the relative reflective index and wavelength of incident light are needed to determine and the Mie scattering efficiency is calculated finally (Mätzler, 2002):

$$Q_{\beta(\theta)} = \frac{1}{2\pi x^2}(S_1 S_1^* + S_2 S_2^*) \tag{14}$$

However mix particle size result and VSF can't be obtained via the code, Song Qingjun added functions as follows:

$$\beta(\theta) = C_i \frac{\pi}{4} D^2 Q_{\beta(\theta)} \tag{15}$$

For mix particle size, it is the sum of each single particle size result:

$$\beta(\theta) = \sum_d C_{id} \frac{\pi}{4} D_d^2 Q_{\beta d} \tag{16}$$

In Equation (15), C_i is particle number concentration which unit is m^{-3}. But the data of LISST-100X is volume concentration C_v which unit is μl/L. Thus, regarding the particles as microspheres and converting C_v to C_i:

$$V_m = \frac{1}{6}\pi D^3 \tag{17}$$

$$C_i = \frac{C_v}{V_m} \tag{18}$$

Additionally, for calculating m_{OS}, m_{QO} and b_b, with the guidance of Song Qingjun, further improve the code combining with iterative method, t test and polynomial fitting.

2.3.3 Measuring Particles Size: Mie scattering intensity is the function of three parameters - λ, m and D. For better calibration, the working wavelength of DAWN - 658nm is taken as λ. And m is determined by the kind of particles in samples, for example, $m_{QS} = 1.547$. It is worth noting that m_{OS} is unknown and there are both quartz sand and oil particles usually mixed in water actually in field which the oil particles may adhere to the sand and causing the reflective index differs from m_{QS} and m_{OS}. Thus, m_{OS} and m_{QO} should be estimated. Finally, D can be measured by using the LISST-100X, however, particles size in water is not a single but various, so it need to sum each scattering intensity of single diameter particles. At the time of measuring, a laser emitted from one side of the water groove of LISST-100X, and 32 ring-detectors on the other side can measure signal on 32 angles and convert to data of volume concentration finally. Type B instrument of LISST-100X used in test can measure the diameter from 1.25 to 250μm which divided into 32 interval. The angles and corresponding median size are shown in Table 2:

Table 2. Measurement Angles and Size of LISST-100X Type B

θ / °	D / μm	θ / °	D / μm	θ / °	D / μm	θ / °	D / μm
0.106	1.44	0.4	5.21	1.5	19.5	5.64	72.8
0.125	1.68	0.47	6.14	1.77	23	6.65	85.9
0.148	1.97	0.56	7.24	2.09	27.1	7.85	101
0.174	2.31	0.66	8.54	2.46	31.9	9.26	119
0.206	2.72	0.77	10.1	2.91	37.6	10.93	140
0.243	3.19	0.91	11.9	3.43	44.4	12.9	166
0.287	3.76	1.08	14	4.05	52.4	15.22	196
0.338	4.43	1.27	16.5	4.78	61.7	17.96	231

The size of quartz sand is 800 mesh which is equivalent to 15μm. But in actual data, the small size and large size data are high, which will lead the higher result if do not remove, thus exclude the data of 8 diameter - 1.44, 1.68, 1.97, 2.31, 140, 166, 196 and 231μm. In addition, in order to do calibration, θ should be determined as 18 angles of the angle channels of DAWN as VSF is related to θ. After determining D, m, λ and θ, the theory value of VSF can be obtained via the code. However $\beta_L(\theta)$ of QS sample can be obtained only even if measure all the sample by using two instruments as m_{OS} and m_{QO} are unknown. $\beta_L(\theta)$ of other samples must be obtained after estimating m_{OS} and m_{QO}.

2.4 Calibration of Wyatt Dawn Heleos II

2.4.1 Measuring the Scattering Intensity: DAWN, the instrument of measuring scattering intensity, can not output the value of $\beta_D(\theta)$ but voltage. The 18 detectors on different angles - 22.5°, 28°, 32°, 38°, 44°, 50°, 57°, 64°, 72°, 81°, 90°, 99°, 108°, 117°, 126°, 134°, 141° and 147° can measure the signal of scattering by the 658nm laser.
The samples are the same as those measured by using LISST-100X. To eliminate the error result from uneven thickness of the cuvette, even if it reaches considerable uniformity when it produced, it is necessary that rotating the cuvette during measuring. In addition, when two unequal forces - gravity and buoyancy acting on the particles, they will sink or float and causing the particles distribute unevenly. Thus it is necessary that shaking up the sample before measuring and the measurement time should not longer than 2 minutes.

2.4.2 Calibration: Calibration, basing on $\beta_L(\theta)$, should be done as the output data of DAWN is the voltage value and $\beta_D(\theta)$ can be obtain only via the calibration formula and coefficient. From the part of 2.4.1 of the test, $\beta_L(\theta)$ of 18 angles and voltage value data has obtained, using Excel to fit the data via various method and choose the best as the calibration formula. The fitting result on the angle of 22.5° is shown in Figure 3. which shows that the power function is the best fitting. And the power function is the best fitting for the remaining 17 angles. As a result, use the power function to be the calibration formula. Table 3 shows the calibration coefficient on 18 angles. Finally, it can convert the voltage value to $\beta_D(\theta)$ via the calibration result.
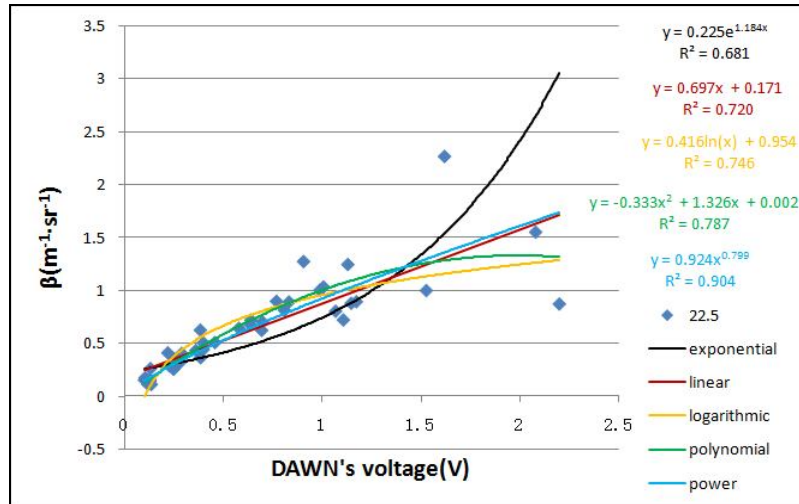

Figure 3. Fitting Result on 22.5°

Table 3. Different Angles' Calibration Result of Formula - $y = ax^b$

θ	a	b	R^2	θ	a	b	R^2
22.5°	0.924	0.799	0.904	81°	0.091	0.768	0.931
28°	0.849	0.78	0.895	90°	0.09	0.772	0.914
32°	0.559	0.778	0.885	99°	0.151	0.787	0.897
38°	0.459	0.761	0.889	108°	0.314	0.788	0.813
44°	0.368	0.749	0.872	117°	0.251	0.818	0.878
50°	0.146	0.764	0.9	126°	0.159	0.836	0.866
57°	0.151	0.761	0.914	134°	0.07	0.841	0.861
64°	0.087	0.761	0.911	141°	0.16	0.851	0.837
72°	0.104	0.756	0.911	147°	0.075	0.86	0.823

2.5 Estimating the Reflective Index

According to the simplest idea, the inverse operation of Mie scattering model can calculate the reflective index, but the part of 2.2.2 shows that $\beta_L(\theta)$ can be obtain after obtaining $Q_{\beta(\theta)}$, after calculating S_1 and S_2, and after working out a_N, b_N, τ_N and π_N. a_N and b_N are the functions relating m, λ and D while τ_N and π_N are the functions relating θ. It can draw a conclusion that there are several processes of calculating a parameter from a number of parameters as is shown in Figure 4:

$$
\left.\begin{array}{l}
aN(m,\lambda,D) \\
bN(m,\lambda,D) \\
\pi N(\theta) \\
\tau N(\theta)
\end{array}\right\} =>
\left.\begin{array}{l}
S1(aN,bN,\pi N,\tau N) \\
S2(aN,bN,\pi N,\tau N)
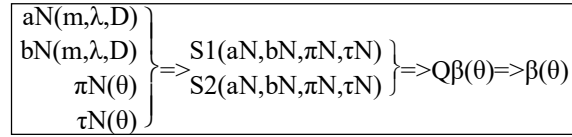\end{array}\right\} => Q\beta(\theta) => \beta(\theta)
$$

Figure 4. Processes of calculating

It is obviously impossible that obtain a parameter from a number of parameters via the inverse operation idea. For example, the product - mx in function (5) and function (6), will not change if m becomes 2 times and x does 1/2. In other words, it can not calculate the value of m and x even if the value of mx is known. As the inverse operation idea does not work, the iterative method is used to estimate the reflective index. By this method, firstly given an initial index to calculate $\beta_L(\theta)$, and then contrast $\beta_L(\theta)$ and $\beta_D(\theta)$ via t-test and obtain the event probability - P which shows less different if more close to 1. And repeat the process of increase the index, calculate $\beta_L(\theta)$ again, do t-test, compare P to the last one, until the P value is the most close to 1. Then calculate the average value of different samples of OS samples as m_{OS}, and m_{QO} is obtained by the same way. Finally, substituting the result of m_{OS} and m_{QO} into the code, obtain $\beta_D(\theta)$ of OS samples and QO samples and analyze the result. Part of reflective index of OS samples and QO samples are shown in Table 4 as follow.

Table 4. Part of Reflective Index

OS samples (ml/L)	P	m	QO samples (mg/L, ml/L)	P	m
50	0.995	1.451	5,50	0.998	1.461
100	0.992	1.455	10,100	0.994	1.486
200	0.995	1.454	20,200	0.996	1.476
300	0.999	1.453	30,300	0.998	1.466

2.6 Calculation of Backscattering Coefficient

The formula of b_b is shown as the following Equation which can be regarded as the result of integral of a continuous function - $\beta(\theta)\sin(\theta)$. However there are only 7 detectors on backscattering angles in DAWN - 99°, 108°, 117°, 126°, 134°, 141° and 147°. The angles distribute sparsely causing the large error if calculate via trapezoidal integration. So it should use another method to calculate.

$$b_b = 2\pi \int_{\pi/2}^{\pi} \beta(\theta)\sin(\theta)d\theta \tag{19}$$

From the point of view of the definition of integral, the formula can be regarded as ' 2π times the difference of the primitive function of $\beta(\theta)\sin(\theta)$ between the upper and lower limit'. As a result using the polynomial fitting to obtain the polynomial function to substitute $\beta(\theta)\sin(\theta)$ which can be convert to the primitive function. The polynomial function is shown as follow:

$$\beta(\theta)\sin(\theta)=a_0+a_1\theta^1+a_2\theta^2+a_3\theta^3+...+a_n\theta^n \tag{20}$$

Mankovsky has obtained a series VSF on the angles that distribute intensive. Song Qingjun (2008) has calculated the b_b via the method of integral and polynomial fitting, compared the result, and found that cubic polynomial can achieve sufficient accuracy. Finally, $\beta(\theta)\sin(\theta)$ should be converted as Equation (20):

$$f(\theta)=\beta(\theta)\sin(\theta)= a_0+a_1\theta^1+a_2\theta^2+a_3\theta^3 \tag{21}$$

Besides 7 scattering angles, $\theta = \pi$ should be added because $\sin(\pi) = 0$, during the process of polynomial fitting. Suppose $F(\theta)$ is the primitive function of $f(\theta)$, and the final equation is shown as follow:

$$b_b = 2\pi[F(\pi)-F(\pi/2)] = 2\pi\Delta F \tag{22}$$

$$b_b = 2\pi\{a_0(\pi-\frac{\pi}{2})+\frac{a_1}{2}[\pi^2-(\frac{\pi}{2})^2]+\frac{a_2}{3}[\pi^3-(\frac{\pi}{2})^3]+\frac{a_3}{4}[\pi^4-(\frac{\pi}{2})^4]\} \tag{23}$$

3. RESULT AND ANALYSIS

Table 5 shows the p value of t-test with VSF obtained via two methods. $\beta_{LO}(\theta)$ and $\beta_{DO}(\theta)$ are the VSF of OS samples, $\beta_{LM}(\theta)$ and $\beta_{DM}(\theta)$ are the VSF of QO samples. Though the p value closing to 1 which means VSF of two methods are similar, b_b must analyze below as it plays an important role in ocean color RS.

Table 5. Compare of P Value of VSF between two Methods

compare $\beta_{LO}(\theta)$ & $\beta_{DO}(\theta)$		compare $\beta_{LM}(\theta)$ & $\beta_{DM}(\theta)$	
OS samples(ml/L)	P	QO samples(mg/L,ml/L)	P
50	0.954	5,50	0.828
100	0.985	10,100	0.829
200	0.988	20,200	0.960
300	0.992	30,300	0.907

3.1 Compare of Backscattering of VSF

Figure 5 shows that the backscattering of VSF of QS samples two method -$\beta_{LQb}(\theta)$ and $\beta_{DQb}(\theta)$ are more similar than other samples though do not coincide well which indicates there is a certain error on backscattering which is shown in R^2 of Table 3 too. Furthermore monotonicity of $\beta_{Db}(\theta)$ of three samples are similar which shows that the backscattering are similar too.
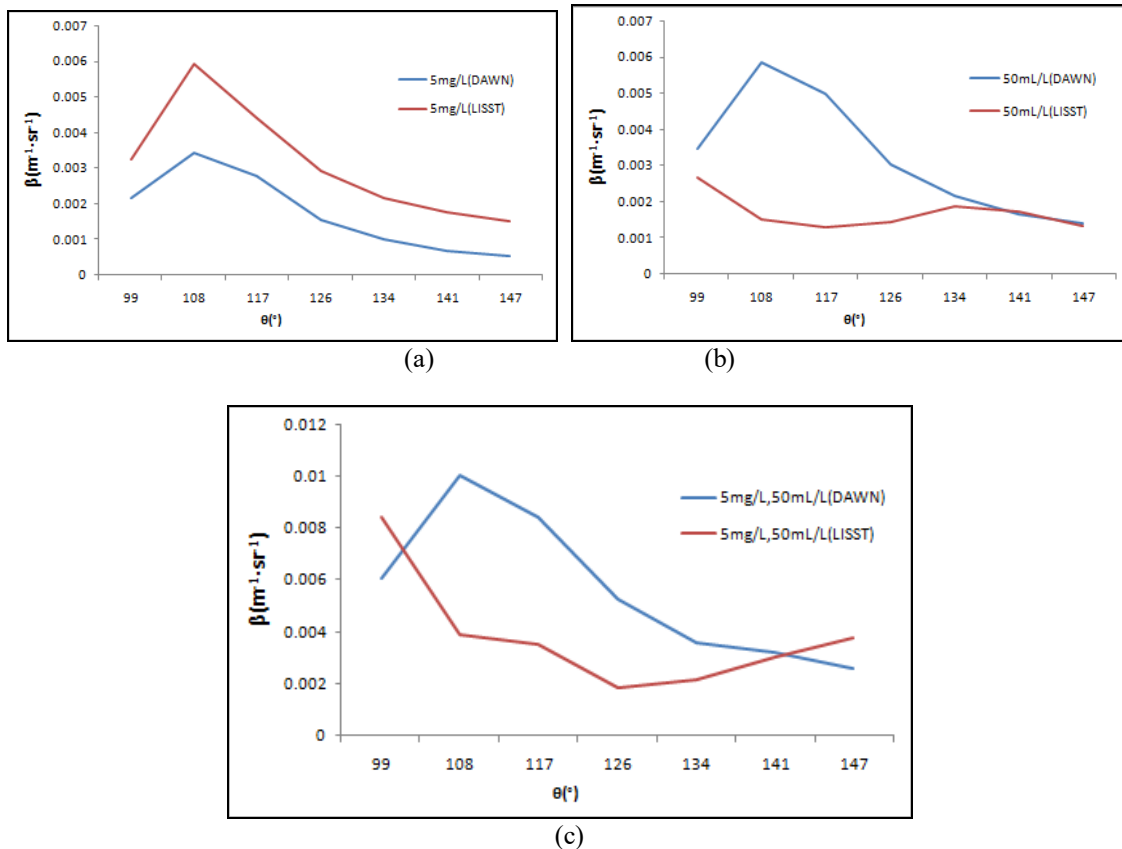

(a)   (b)

(c)

Figure 5. Compare of VSF of QS samples (a), OS samples (b), and QO samples (c) between two Methods

However, monotonicity of $\beta_{Lb}(\theta)$ of three samples are different not only in this test but also the situation of the λ and D are invariant except for m which is shown in Figure 6. This may be a large error in the estimation of index of refraction index.
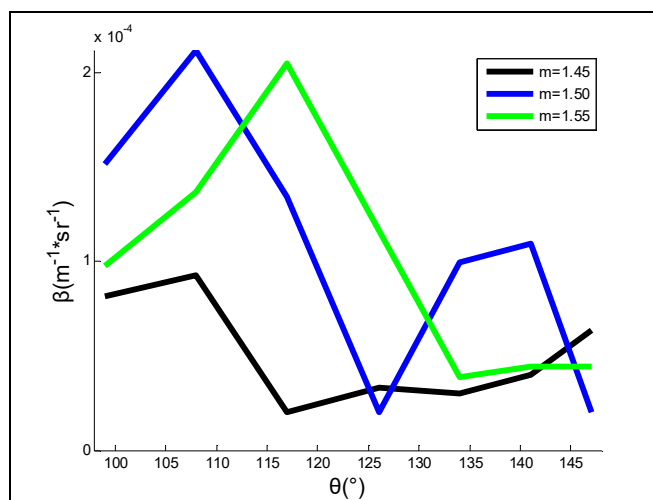

Figure 6. Theory Value of $\beta_{Lb}(\theta)$ on Different m

It is different that the results obtained via the two methods. According to the measurement principle of the LISST-100X, light signal on small scattering angles can be measured and converted to volume concentration. And OS samples of which the components is more complicated than the samples that includes oil and pure water are collected from the field. The above will occur when there are some particles which are different size from that of quartz sand but the contribution to the backscattering is similar to that of quartz sand.

3.2 Compare of Backscattering Coefficient

It is shown in Table 6 that the difference of b_b between two methods is less in the case of low concentration than high concentration. The difference of b_b of OS samples is the least which seems contradictory to the analysis in part 3.1. Analyzing from the angle of calculating of integral and Equation (21), the value of backscattering coefficient is determined by ΔF. In other words ΔF will not change if $F(\pi)$ and $F(\pi / 2)$ increase or decrease at same amplitude in the case of considering ΔF only. As a result it is not contradictory to the analysis in part 3.1. Furthermore, Figure 7 shows the obvious difference between the value of $F(\pi)$ and $F(\pi / 2)$ of two methods. Figure 5 shows the little difference between the value of $\beta(99°)$-$\beta(147°)$ of two methods. This property is retained after polynomial fitting and causing little difference between ΔF which indicates there is a certain error on backscattering. As a result, the little difference between b_b of two methods does not mean $\beta_{Db}(\theta)$ and $\beta_{Lb}(\theta)$ are similar.

Table 6. Compare of Backscattering Coefficient between two Methods

| samples and concentration		LISST $(b_{bL})(m^{-1})$	DAWN $(b_{bD})(m^{-1})$	difference $(b_{bL} - b_{bD})$	average of difference
QS samples (mg/L)	5	0.017268	0.008984	0.008283	0.009195
	10	0.025396	0.020012	0.005384	
	20	0.050221	0.036081	0.01414	
	30	0.059147	0.050177	0.008971	
OS samples (ml/L)	50	0.015824	0.016481	-0.00066	0.005585
	100	0.030404	0.028432	0.001972	
	200	0.057871	0.051081	0.006789	
	300	0.085233	0.070998	0.014235	
QO samples (mg/L,ml/L)	5,50	0.038341	0.029263	0.009078	0.020224
	10,100	0.04699	0.044211	0.002779	
	20,200	0.095492	0.075374	0.020118	
	30,300	0.16142	0.112499	0.048922	
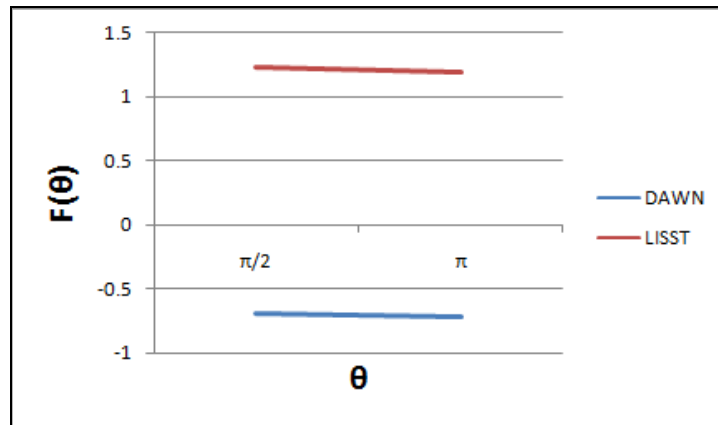
Figure 7. F(π) and F(π / 2) of two Methods

3.3 Error Analysis

In principle analysis, scattering occurs when particles is being illuminated by light in medium, and therefore different wavelength of light, different medium and different situation of the particles in medium will lead to changes in scattering phenomena. In this test the wavelength determined as 658nm and medium as pure water which means the main error is caused by the situation of the particles. The possible factors are summarized as follows: Firstly, there are various kinds of particles which may adhere mutually in OS samples. Secondly besides adherence, the particles may also degrade. Thirdly after quartz sand and particles in oil-pollute water adhere mutually in QO samples, there will be various situations of adherence such as two separate particles of the sand and oil, adherent particles of several sand and several oil particles etc. Fourthly adherence may happen between quartz sand particles. The above factors cause it is not well explained for the phenomenon in Figure 5.

From data analysis, on the angles between 0 to 45° β(θ) decreases rapidly. $β_b(θ)$ which value is about 1/10 of β(45°) changes little. As a result the error of backscattering is little relatively during calibration and t-test which lead to the little difference of VSF while large difference of $β_b(θ)$.

4. SUMMARY AND PROSPECT

From the result, the error of the backscattering is obvious, which is mainly caused by the uncertainty of the particles and the error of the estimated reflective index. Therefore, the improvements are listed as follow: Firstly, using the oil standard material and pure water to prepare the OS samples. Secondly, seek the way of wrapping all the quartz sand by oil precisely and uniformly for preparing the QO samples. Thirdly, the error of backscattering should be reduced to the minimum during estimating the reflective index. Additionally, there are certain limitations in this test as using only the LISST-100X, Wyatt dawn II Heleos, Mie scattering model of measurement and analysis. For better analyze the phenomenon of the test, HS-6 should be used and compare and analyze the results further. As to the feasibility of these two methods to measure the backscattering coefficient is needed to be further explored.

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