# 杉木综纤维素和木质素的近红外光谱法测定

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**摘 要**用近红外光谱法对杉木中综纤维素和木质素含量进行了快速测定。用常规湿化学方法测定了48个 杉木木材样品的综纤维素和木质素,用近红外光谱仪采集相应的光谱,进行二阶微分处理和平滑预处理后, 用偏最小二乘法和完全交互验证方式建立相应预测模型。综纤维素校正模型和预测模型的相关系数分别为 0.96和0.93;预测标准误差分别为0.39和0.50;木质素校正模型和预测模型的相关系数分别为0.99和 0.90;预测标准误差分别为0.10和0.28。结果表明,近红外光谱法可以快速分析木材中综纤维素和木质素 含量。

关键词 近红外光谱;综纤维素;木质素 中图分类号: S781.4 文献标识码: A

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# 引 言

近红外(near infrared, NIR)光谱分析技术是一类新型的 分析技术,它不是采用传统的研究谱峰归属,再进行定性、 定量分析光谱的研究模式,而是采用化学计量学中的多元校 正方法,以及现代光学、计算机数据处理技术发展起来的现 代分析技术<sup>[1]</sup>。近红外光的能量与分子振动能量相当,人们 将 780~2 500 nm 光谱区定义为近红外光谱区,近红外光谱 主要是含氢基团,如 C-H,O-H,N-H等基团伸缩振动 的倍频吸收谱带及伸缩振动和摇摆振动的合频吸收<sup>[2]</sup>。木材 的主要成分综纤维素和木质素是两种天然高分子聚合物,分 子内大量的含氢基团使其在近红外区域具有丰富的吸收<sup>[3]</sup>。

综纤维素(包括纤维素和半纤维素)和木质素是组成木材 的主要成分,它们与木材其他性质以及木材的加工利用密切 相关。在造纸工业中,纤维素含量多少与纸浆得率和纸浆质 量密切相关;木质素的含量是制定蒸煮和漂白工艺条件的重 要依据<sup>[4,5]</sup>。现在测量造纸原料中综纤维素含量的方法主要 是依据国家标准,首先用苯-醇溶液抽提试样,然后用水、冰 醋酸、亚氯酸钠的混合溶液酸解三到四次,再进行抽吸过 滤;测量一个样品的化学成分含量,一个有经验的试验员大 约需要耗费 2~4 d的时间。木质素的测量同样比较繁琐、费 时。因此,无法满足林木培育和木材工业中大批量样品的测 定需求<sup>[6-9]</sup>。

近红外光谱法是一种准确、无损的快速分析方法,近年

来在木材科学研究方面得到了越来越多的重视。国外在木材的化学性质、物理性质、力学性质等方面都做了一些研究<sup>[10-15]</sup>,国内,中国林业科学研究院已经就近红外光谱法预测木材密度、微纤丝角、结晶度、腐朽性质等方面进行了研究<sup>[16-20]</sup>。

本文首先按照湿化学方法测定了人工林杉木木材的综纤 维素和木质素含量,利用近红外光谱技术结合偏最小二乘 法,分析了我国特有的人工林树种杉木木材的综纤维素、木 质素含量,这对实现木材化学成分的快速、准确测定以及促 进近红外光谱技术在我国木材科学与造纸工业中的应用具有 重要意义。

## 1 实验部分

## 1.1 试剂与仪器

亚氯酸钠(74.6%),工业纯;苯、乙醇、冰醋酸、丙酮、 硫酸均为分析纯。

人工林杉木试材采自于安徽省黄山林场,从不同海拔高 度伐取6株,每株从胸高处开始,每隔2m截取一个6cm圆 盘,气干后分心边材分别劈成小薄片,经过粉碎,筛分,最 后选取40~60目的木粉,供分析和采谱用,共制得样品48 个。

美国 ASD 公司生产的 LabSpec Pro 近红外光谱仪,采用 漫反射积分球附件,扫谱范围: 350~2 500 nm,低噪声 512 阵元 PDA;光谱采样间隔: 1.4 nm@350~1 050 nm; 2 nm@

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1 000~2 500 nm; 光谱分辨率: 3 nm@700 nm; 10 nm@ 1 400, 2 100 nm。

## 1.2 综纤维素和酸不溶木质素含量测定

综纤维素和酸不溶木质素含量的测定分别按照国标 GB/ T 2677.10—1995 和 GB/T 2677.8—94 进行。同时做两份平 行样测定,取其算术平均值作为测定值。

### 1.3 NIR 光谱采集

近红外光谱仪和光谱采集均在装有空调的恒温 (20±2)℃室内进行。用杯光源检测器对商用聚四氟乙烯白 板进行空白校准后,再对样品的近红外光谱在全光谱范围内 (350~2 500 nm)进行采集,每次扫描 30 次并自动平均为一 个光谱,每个样品采谱 3 次,取平均值。

# 2 结果与讨论

#### 2.1 不同木材成分的近红外光谱特征

木材是复杂的天然聚合物质,其主要组成为纤维素、半 纤维素和木质素等高分子有机物,这些成分在近红外区都有 较强的吸收。如图1所示,杉木木材的主要成分在波长 1440,1910,2100,2270mm处有较强的吸收峰。同时我 们看到,近红外光谱的谱带较宽,谱峰重叠严重,因此,近 红外光谱不能像中红外光谱那样明确地确定谱带的归属。化 学计量学和计算机技术的快速发展,使得近红外光谱作为常 规分析技术的应用成为可能,该法具有准确、快速、可靠、 无破坏性、可在线实时进行检测与监控等特点。



Fig. 1 Near infrared diffuse reflectance spectra of Chinese fir

## 2.2 综纤维素含量近红外分析模型的建立

综纤维素含量的最大值为 72.46%,最小值为 66.82%, 平均值为 69.41%。综纤维素近红外漫反射光谱分析模型的 建立采用 CAMO 公司的多变量统计分析软件 Unscrambler9.2中的偏最小二乘法(PLS1),波长范围为 1 000~2 500 nm,预处理方法为 25 点平滑和二阶导数处理,采用完全交 互验证方式(Full cross validation)确定校正集主成分的最佳 主成分数为 4。综纤维素 NIR 分析模型相关系数 r 校正集为 0.96,检验集为 0.93,校正标准误差 SEC 为 0.39,预测标准 误差 SEP 为 0.50。综纤维素含量的化学测定值与模型预测 值的相关关系散点图见图 2,详细数据见表 1。

### 2.3 木质素素含量近红外分析模型的建立

木质素含量的最大值为 35.28%, 最小值为 32.26%, 平



采用 CAMO 公司的多变量统计分析软件 Unscrambler9.2 中的偏最小二乘法(PLS1),波长范围为 350~2 500 nm,预处 理方法为 25 点平滑和二阶导数处理,采用完全交互验证方式确定校正集主成分的最佳主成分数为 11。木质素 NIR 分析模型相关系数(r)校正集为 0.99,检验集为 0.90,校正标准误差 SEC 为 0.10,预测标准误差 SEP 为 0.28。木质素含量的化学测定值与模型预测值的相关散点图见图 3,化学测定与预测值详细数据见表 1。

## 3 结 论

本文用近红外光谱漫反射法对杉木中综纤维素和木质素 含量进行了快速测定。用常规湿化学方法测定了 48 个杉木 木材样品的综纤维素和木质素含量,用近红外光谱仪测定相 应的光谱,进行二阶微分和 25 点平滑预处理后,用偏最小二 乘法和完全交互验证方式建立相应模型。综纤维素校正模型 和预测模型的相关系数 r 分别为 0.96,0.93,校正标准误差 SEC 为 0.39,预测标准误 SEP 为 0.50;木质素的校正模型 和预测模型的相关系数 r 分别为 0.99,0.90,校正标准误差 SEC 为 0.10,预测标准误 SEP 为 0.28。以上分析表明,近红

## 外光谱法可以快速分析木材中综纤维素和木质素含量。

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1572. 1171. 48 $-0. 63$ $-0. 87$ 32. 63 $32. 69$ $0. 06$ $0. 18$ 1669. 6969. 50 $-0. 19$ $-0. 27$ $32. 71$ $32. 85$ $-0. 06$ $-0. 17$ 1771. 1171. 66 $0. 55$ $0. 77$ $32. 39$ $32. 80$ $0. 41$ $1. 27$ 1869. 9669. 55 $-0. 41$ $-0. 58$ $32. 56$ $22. 36$ $-0. 20$ $-0. 61$ 1972. 4671. 95 $-0. 51$ $-0. 71$ $32. 36$ $33. 59$ $-0. 20$ $-0. 60$ 2069. 9269. 48 $-0. 44$ $-0. 63$ $33. 79$ $33. 59$ $-0. 20$ $-0. 60$ 2172. 6671. 48 $-0. 58$ $-0. 22$ $-0. 32$ $33. 43$ $33. 54$ $-0. 38$ $-1. 13$ 2269. 2869. 06 $-0. 22$ $-0. 27$ $32. 68$ $33. 61$ $0. 25$ $0. 74$ 2468. 5569. 23 $0. 68$ $0. 99$ $33. 36$ $33. 61$ $0. 25$ $0. 74$ 2567. 6268. 02 $0. 40$ $0. 59$ $33. 49$ $33. 93$ $0. 43$ $1. 30$ 2669. 80 $70. 24$ $0. 44$ $0. 64$ $33. 56$ $33. 31$ $-0. 26$ $-0. 76$ 2766. 9167. 36 $0. 45$ $0. 67$ $33. 81$ $33. 53$ $-0. 28$ $-0. 83$ 2869. 8369. 90 $0. 52$ $0. 75$ $34. 11$ $33. 79$ $-0. 32$ $-0. 83$ 2966. 82 $66. 85$ $0. 03$ <td< td=""><td>14</td><td>69.55</td><td>69.65</td><td>0.10</td><td>0.14</td><td>32.83</td><td>33.29</td><td>0.46</td><td>1.40</td></td<>	14	69.55	69.65	0.10	0.14	32.83	33.29	0.46	1.40	
1669, 6969, 50 $-0.19$ $-0.27$ $32.71$ $32.65$ $-0.06$ $-0.17$ 1771, 1171, 66 $0.55$ $0.77$ $32.39$ $32.80$ $0.41$ $1.27$ 1869, 9669, 55 $-0.41$ $-0.58$ $32.56$ $32.36$ $-0.20$ $-0.61$ 1972, 4671.95 $-0.51$ $-0.71$ $32.36$ $22.57$ $0.21$ $0.66$ 2069, 9269, 48 $-0.44$ $-0.63$ $33.79$ $33.59$ $-0.20$ $-0.60$ 2172.0671, 48 $-0.58$ $-0.81$ $33.44$ $33.46$ $-0.38$ $-1.13$ 2269.2869.06 $-0.22$ $-0.32$ $33.43$ $33.51$ $0.08$ $0.23$ 2371.5071.30 $-0.20$ $-0.27$ $32.66$ $32.80$ $0.12$ $0.38$ 2468.5569.23 $0.68$ $0.99$ $33.36$ $33.61$ $0.25$ $0.74$ 2567.6268.02 $0.40$ $0.59$ $33.36$ $33.31$ $-0.26$ $-0.76$ 2766.9167.36 $0.45$ $0.67$ $33.81$ $33.53$ $-0.28$ $-0.83$ 2869.8369.94 $0.11$ $0.16$ $34.00$ $33.99$ $-0.01$ $-0.02$ 3069.3869.94 $0.52$ $0.75$ $34.11$ $33.79$ $-0.32$ $-0.94$ 3167.6467.98 $0.34$ $0.50$ $34.00$ $33.99$ $-0.01$ $-0.02$ 3268.83 $0$	15	72.11	71.48	-0.63	-0.87	32.63	32.69	0.06	0.18	
1771.1171.66 $0.55$ $0.77$ $32.39$ $32.80$ $0.41$ $1.27$ 18 $60.96$ $69.55$ $-0.41$ $-0.58$ $32.56$ $32.36$ $-0.20$ $-0.61$ 19 $72.46$ $71.95$ $-0.51$ $-0.71$ $32.36$ $32.57$ $0.21$ $0.66$ 20 $69.92$ $69.48$ $-0.44$ $-0.63$ $33.79$ $33.59$ $-0.20$ $-0.60$ 21 $72.06$ $71.48$ $-0.58$ $-0.81$ $33.84$ $33.46$ $-0.38$ $-1.13$ 22 $69.28$ $69.06$ $-0.22$ $-0.32$ $33.43$ $33.51$ $0.08$ $0.23$ 23 $71.50$ $71.30$ $-0.20$ $-0.27$ $32.68$ $32.80$ $0.12$ $0.38$ 24 $68.55$ $69.23$ $0.68$ $0.99$ $33.36$ $33.61$ $0.25$ $0.74$ 25 $67.62$ $68.02$ $0.40$ $0.59$ $33.49$ $33.93$ $0.43$ $1.30$ 26 $69.80$ $70.24$ $0.44$ $0.64$ $33.56$ $33.31$ $-0.26$ $-0.76$ 27 $66.81$ $67.36$ $0.45$ $0.67$ $33.81$ $33.53$ $-0.28$ $-0.83$ 28 $69.83$ $69.94$ $0.11$ $0.16$ $34.00$ $33.91$ $-0.09$ $-0.28$ 29 $66.82$ $66.85$ $0.03$ $0.44$ $33.76$ $33.80$ $0.04$ $0.12$ 30 $69.38$ $69.90$ $0.52$ $0.75$ $34.11$ $33.79$ $0.31$ $0.93$ <	16	69.69	69.50	-0.19	-0.27	32.71	32.65	-0.06	-0.17	
1869.9669.55 $-0.41$ $-0.58$ $32.56$ $32.36$ $-0.20$ $-0.61$ 1972.4671.95 $-0.51$ $-0.71$ $32.36$ $32.57$ $0.21$ $0.66$ 2069.9269.48 $-0.44$ $-0.63$ $33.79$ $33.59$ $-0.20$ $-0.60$ 2172.0671.48 $-0.58$ $-0.13$ $33.44$ $33.46$ $-0.38$ $-1.13$ 2269.2869.06 $-0.22$ $-0.32$ $33.43$ $33.51$ $0.08$ $0.23$ 2371.5071.30 $-0.20$ $-0.27$ $32.68$ $32.80$ $0.12$ $0.38$ 2468.5569.23 $0.68$ $0.99$ $33.36$ $33.61$ $0.25$ $0.74$ 2567.6268.02 $0.40$ $0.59$ $33.49$ $33.93$ $0.43$ $1.30$ 2669.8070.24 $0.44$ $0.64$ $33.56$ $33.31$ $-0.28$ $-0.83$ 2869.8369.94 $0.11$ $0.67$ $33.81$ $33.53$ $-0.28$ $-0.83$ 2966.8266.85 $0.03$ $0.04$ $33.76$ $33.80$ $0.04$ $0.12$ 3069.3869.90 $0.52$ $0.75$ $34.11$ $33.79$ $-0.32$ $-0.94$ 3167.6467.98 $0.34$ $0.50$ $34.00$ $33.99$ $-0.01$ $-0.02$ 3268.2768.48 $0.21$ $0.11$ $33.60$ $33.54$ $0.41$ $1.24$ 3467.6967.83 $0.1$	17	71.11	71.66	0.55	0.77	32.39	32.80	0.41	1.27	
1972.4671.95-0.51-0.7132.3632.570.210.662060.9269.48-0.44-0.6333.7933.59-0.20-0.602172.0671.48-0.58-0.8133.4333.45-0.38-1.132269.2869.06-0.22-0.3233.4333.510.080.232371.5071.30-0.20-0.2732.6832.800.120.382468.5569.230.680.9933.3633.610.250.742567.6268.020.400.5933.4933.930.431.302669.8070.240.440.6433.5633.31-0.26-0.762766.8167.360.450.6733.8133.53-0.28-0.832869.8369.940.110.1634.0033.91-0.09-0.223069.3869.900.520.7534.1133.79-0.32-0.943167.6467.980.340.5034.0033.99-0.1-0.023268.2768.480.210.3133.6033.910.310.933369.5070.030.530.7633.1333.540.411.243467.6967.830.140.2033.3832.99-0.19-0.573568.950.560.8233.4833.790.31<	18	69,96	69. 55	-0.41	-0.58	32, 56	32, 36	-0.20	-0.61	
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	19	72.46	71.95	-0.51	-0.71	32.36	32.57	0.21	0.66	
2172.0671.48-0.58-0.8133.8433.46-0.32-1.132269.2869.06 $-0.22$ $-0.32$ 33.4333.510.080.232371.5071.30 $-0.20$ $-0.27$ 32.6832.800.120.382468.5569.230.680.9933.3633.610.250.742567.6268.020.400.5933.4933.930.431.302669.8070.240.440.6433.5633.31 $-0.26$ $-0.76$ 2766.9167.360.450.6733.8133.53 $-0.28$ $-0.83$ 2869.8369.940.110.1634.0033.91 $-0.09$ $-0.22$ 2966.850.030.0433.7633.800.040.123069.3869.900.520.7534.1133.79 $-0.32$ $-0.94$ 3167.6467.980.340.5034.0033.91 $0.31$ $0.93$ 3369.5070.030.530.7633.1333.540.411.243467.6967.830.140.2033.3833.29 $-0.09$ $-0.27$ 3568.3968.950.560.8233.4833.790.310.933669.7069.23 $-0.47$ $-0.67$ 33.1533.160.010.023768.4167.94 $-0.47$ $-0.67$	20	69.92	69, 48	-0.44	-0.63	33.79	33, 59	-0.20	-0.60	
1269.2869.06 $-0.22$ $-0.32$ $33.43$ $33.51$ $0.08$ $0.23$ 2371.5071.30 $-0.20$ $-0.27$ $32.68$ $32.80$ $0.12$ $0.38$ 2468.5569.23 $0.68$ $0.99$ $33.36$ $33.61$ $0.25$ $0.74$ 2567.6268.02 $0.40$ $0.59$ $33.49$ $33.93$ $0.43$ $1.30$ 2669.8070.24 $0.44$ $0.64$ $33.56$ $33.31$ $-0.26$ $-0.76$ 2766.9167.36 $0.45$ $0.67$ $33.81$ $33.53$ $-0.28$ $-0.83$ 2869.8369.94 $0.11$ $0.16$ $34.00$ $33.91$ $-0.09$ $-0.23$ 2966.8266.85 $0.03$ $0.04$ $33.76$ $33.80$ $0.04$ $0.12$ 3069.3869.90 $0.52$ $0.75$ $34.11$ $33.79$ $-0.32$ $-0.94$ 3167.6468.48 $0.21$ $0.31$ $33.60$ $33.91$ $-0.01$ $-0.02$ 3268.97 $0.56$ $0.82$ $33.48$ $33.79$ $0.31$ $0.93$ 3369.5070.03 $0.53$ $0.76$ $33.15$ $33.16$ $0.01$ $0.27$ 3568.3968.95 $0.56$ $0.82$ $33.48$ $33.79$ $0.31$ $0.93$ 3669.70 $69.24$ $-0.12$ $-0.67$ $33.15$ $33.16$ $0.01$ $0.02$ 3768.41 $67.63$ $-0.80$ $-1.17$ <	21	72.06	71.48	-0.58	-0.81	33.84	33, 46	-0.38	-1.13	
23 $01.10$ $01.01$ $01.02$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$ $01.01$	22	69. 28	69.06	-0.22	-0.32	33, 43	33, 51	0.08	0. 23	
24 $68.55$ $69.23$ $0.68$ $0.99$ $33.36$ $33.61$ $0.25$ $0.74$ $25$ $67.62$ $68.02$ $0.40$ $0.59$ $33.49$ $33.93$ $0.43$ $1.30$ $26$ $69.80$ $70.24$ $0.44$ $0.64$ $33.56$ $33.31$ $-0.26$ $-0.76$ $27$ $66.91$ $67.36$ $0.45$ $0.67$ $33.81$ $33.53$ $-0.28$ $-0.83$ $28$ $69.83$ $69.94$ $0.11$ $0.16$ $34.00$ $33.91$ $-0.09$ $-0.28$ $29$ $66.82$ $66.85$ $0.03$ $0.04$ $33.76$ $33.80$ $0.04$ $0.12$ $30$ $69.38$ $69.90$ $0.52$ $0.75$ $34.11$ $33.79$ $-0.32$ $-0.94$ $31$ $67.64$ $67.98$ $0.34$ $0.50$ $34.00$ $33.99$ $-0.01$ $-0.02$ $32$ $68.27$ $68.48$ $0.21$ $0.31$ $33.60$ $33.91$ $0.31$ $0.93$ $33$ $69.50$ $70.03$ $0.53$ $0.76$ $33.13$ $33.54$ $0.41$ $1.24$ $34$ $67.69$ $67.83$ $0.14$ $0.20$ $33.38$ $33.29$ $-0.09$ $-0.27$ $35$ $68.39$ $68.95$ $0.56$ $0.82$ $33.48$ $33.79$ $0.31$ $0.93$ $36$ $69.70$ $69.23$ $-0.47$ $-0.67$ $33.15$ $33.57$ $-0.28$ $-0.83$ $39$ $69.93$ $68.94$ $-0.99$ $-1.42$ $35.28$ $34.80$ $-0.48$	23	71.50	71.30	-0.20	-0.27	32, 68	32, 80	0.12	0.38	
25 $67.62$ $68.02$ $0.40$ $0.59$ $33.49$ $33.43$ $0.43$ $1.10$ $26$ $69.80$ $70.24$ $0.44$ $0.64$ $33.56$ $33.31$ $-0.26$ $-0.76$ $27$ $66.91$ $67.36$ $0.45$ $0.67$ $33.81$ $33.53$ $-0.28$ $-0.83$ $28$ $69.83$ $69.94$ $0.11$ $0.16$ $34.00$ $33.91$ $-0.09$ $-0.28$ $29$ $66.82$ $66.85$ $0.03$ $0.04$ $33.76$ $33.80$ $0.04$ $0.12$ $30$ $69.38$ $69.90$ $0.52$ $0.75$ $34.11$ $33.79$ $-0.32$ $-0.94$ $41$ $67.64$ $67.98$ $0.34$ $0.50$ $34.00$ $33.99$ $-0.01$ $-0.02$ $32$ $68.27$ $68.48$ $0.21$ $0.31$ $33.60$ $33.91$ $0.31$ $0.93$ $33$ $69.50$ $70.03$ $0.53$ $0.76$ $33.13$ $33.54$ $0.41$ $1.24$ $34$ $67.69$ $67.83$ $0.14$ $0.20$ $33.38$ $33.29$ $-0.09$ $-0.27$ $35$ $68.39$ $68.95$ $0.56$ $0.82$ $33.48$ $33.79$ $0.31$ $0.93$ $36$ $69.70$ $69.23$ $-0.47$ $-0.67$ $33.15$ $33.16$ $0.01$ $0.02$ $37$ $68.41$ $67.94$ $-0.12$ $-0.17$ $33.85$ $33.57$ $-0.28$ $-0.83$ $39$ $69.36$ $69.24$ $-0.12$ $-0.17$ $33.85$ $33.57$ $-0.$	24	68, 55	69. 23	0.68	0.99	33, 36	33, 61	0. 25	0.74	
26 $61.82$ $61.82$ $61.82$ $61.82$ $61.82$ $61.82$ $61.82$ $61.82$ $61.82$ $61.82$ $61.83$ $61.82$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.93$ $61.83$ $61.93$ $61.83$ $61.93$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.83$ $61.843$ $61.843$ $61.843$ $61.843$ $61.843$ $61.843$ $61.843$ $61.843$ $61.843$ $61.843$ $61.843$ $61.843$ $61.843$ $61.843$ $61.843$ $61.843$ $61.843$ $61.843$ $61.843$ <	25	67.62	68.02	0.40	0.59	33, 49	33, 93	0.43	1.30	
27 $66.91$ $67.36$ $0.45$ $0.67$ $33.81$ $33.53$ $-0.28$ $-0.83$ $28$ $66.83$ $69.94$ $0.11$ $0.16$ $34.00$ $33.91$ $-0.09$ $-0.28$ $29$ $66.82$ $66.85$ $0.03$ $0.04$ $33.76$ $33.80$ $0.04$ $0.12$ $30$ $69.38$ $69.90$ $0.52$ $0.75$ $34.11$ $33.79$ $-0.32$ $-0.94$ $31$ $67.64$ $67.98$ $0.34$ $0.50$ $34.00$ $33.99$ $-0.01$ $-0.02$ $32$ $68.27$ $68.48$ $0.21$ $0.31$ $33.60$ $33.91$ $0.31$ $0.93$ $33$ $69.50$ $70.03$ $0.53$ $0.76$ $33.13$ $33.54$ $0.41$ $1.24$ $34$ $67.69$ $67.83$ $0.14$ $0.20$ $33.38$ $33.29$ $-0.09$ $-0.27$ $35$ $68.95$ $0.56$ $0.82$ $33.48$ $33.79$ $0.31$ $0.93$ $36$ $69.70$ $69.23$ $-0.47$ $-0.67$ $33.15$ $33.16$ $0.01$ $0.02$ $37$ $68.41$ $67.94$ $-0.47$ $-0.68$ $34.10$ $33.92$ $-0.19$ $-0.54$ $38$ $69.36$ $69.24$ $-0.12$ $-0.17$ $33.85$ $33.57$ $-0.28$ $-0.83$ $39$ $69.93$ $68.94$ $-0.99$ $-1.42$ $35.28$ $34.80$ $-0.48$ $-1.36$ $40$ $68.43$ $67.63$ $-0.80$ $-1.17$ $34.03$ $34.25$ $0.22$ <td< td=""><td>26</td><td>69, 80</td><td>70. 24</td><td>0.44</td><td>0.64</td><td>33, 56</td><td>33, 31</td><td>-0.26</td><td>-0.76</td></td<>	26	69, 80	70. 24	0.44	0.64	33, 56	33, 31	-0.26	-0.76	
10.1010.1020.1010.1010.0010.0100.0100.1122860.8369.940.110.1634.0033.91 $-0.09$ $-0.28$ 2966.8266.850.030.0433.7633.800.040.123069.3869.900.520.7534.1133.79 $-0.32$ $-0.94$ 3167.6467.980.340.5034.0033.99 $-0.01$ $-0.02$ 3268.2768.480.210.3133.6033.910.310.933369.5070.030.530.7633.1333.540.411.243467.6967.830.140.2033.3833.29 $-0.09$ $-0.27$ 3568.3968.950.560.8233.4833.790.310.933669.7069.23 $-0.47$ $-0.67$ 33.1533.160.010.023768.4167.94 $-0.47$ $-0.67$ 33.8535.57 $-0.28$ $-0.83$ 3969.9368.94 $-0.99$ $-1.42$ 35.2834.80 $-0.48$ $-1.36$ 4068.4367.63 $-0.80$ $-1.17$ 34.0334.25 $0.22$ $0.64$ 4168.5667.88 $-0.68$ $-0.99$ 34.7034.75 $0.05$ $0.14$ 4269.9470.12 $0.18$ $0.26$ 34.0834.31 $0.23$ $0.67$ 4369.89 <td< td=""><td>27</td><td>66, 91</td><td>67.36</td><td>0.45</td><td>0.67</td><td>33, 81</td><td>33, 53</td><td>-0.28</td><td>-0.83</td></td<>	27	66, 91	67.36	0.45	0.67	33, 81	33, 53	-0.28	-0.83	
29 $66.82$ $66.85$ $0.03$ $0.04$ $33.76$ $33.80$ $0.04$ $0.12$ $30$ $69.38$ $69.90$ $0.52$ $0.75$ $34.11$ $33.79$ $-0.32$ $-0.94$ $31$ $67.64$ $67.98$ $0.34$ $0.50$ $34.00$ $33.99$ $-0.01$ $-0.02$ $32$ $68.27$ $68.48$ $0.21$ $0.31$ $33.60$ $33.91$ $0.31$ $0.93$ $33$ $69.50$ $70.03$ $0.53$ $0.76$ $33.13$ $33.54$ $0.41$ $1.24$ $34$ $67.69$ $67.83$ $0.14$ $0.20$ $33.38$ $33.29$ $-0.09$ $-0.27$ $35$ $68.39$ $68.95$ $0.56$ $0.82$ $33.48$ $33.79$ $0.31$ $0.93$ $36$ $69.70$ $69.23$ $-0.47$ $-0.67$ $33.15$ $33.16$ $0.01$ $0.02$ $37$ $68.41$ $67.94$ $-0.47$ $-0.68$ $34.10$ $33.92$ $-0.19$ $-0.54$ $38$ $69.36$ $69.24$ $-0.12$ $-0.17$ $33.85$ $33.57$ $-0.28$ $-0.83$ $39$ $69.93$ $68.94$ $-0.99$ $-1.42$ $35.28$ $34.80$ $-0.48$ $-1.36$ $40$ $68.43$ $67.63$ $-0.80$ $-1.17$ $34.03$ $34.25$ $0.22$ $0.64$ $41$ $68.56$ $67.88$ $-0.99$ $34.70$ $34.75$ $0.05$ $0.14$ $42$ $69.94$ $70.12$ $0.18$ $0.26$ $34.08$ $34.31$ $0.23$	28	69.83	69 94	0.11	0.16	34 00	33 91	-0.09	-0.28	
30 $69.38$ $69.90$ $0.52$ $0.75$ $34.11$ $33.79$ $-0.32$ $-0.94$ $31$ $67.64$ $67.98$ $0.34$ $0.50$ $34.00$ $33.99$ $-0.01$ $-0.02$ $32$ $68.27$ $68.48$ $0.21$ $0.31$ $33.60$ $33.91$ $0.31$ $0.93$ $33$ $69.50$ $70.03$ $0.53$ $0.76$ $33.13$ $33.54$ $0.41$ $1.24$ $34$ $67.69$ $67.83$ $0.14$ $0.20$ $33.38$ $33.29$ $-0.09$ $-0.27$ $35$ $68.39$ $68.95$ $0.56$ $0.82$ $33.48$ $33.79$ $0.31$ $0.93$ $36$ $69.70$ $69.23$ $-0.47$ $-0.67$ $33.15$ $33.16$ $0.01$ $0.02$ $37$ $68.41$ $67.94$ $-0.47$ $-0.68$ $34.10$ $33.92$ $-0.19$ $-0.54$ $38$ $69.36$ $69.24$ $-0.12$ $-0.17$ $33.85$ $33.57$ $-0.28$ $-0.83$ $39$ $69.93$ $68.94$ $-0.99$ $-1.42$ $35.28$ $34.80$ $-0.48$ $-1.36$ $40$ $68.43$ $67.63$ $-0.80$ $-1.17$ $34.03$ $34.25$ $0.22$ $0.64$ $41$ $68.56$ $67.88$ $-0.68$ $-0.99$ $34.70$ $34.75$ $0.05$ $0.14$ $42$ $69.94$ $70.12$ $0.18$ $0.26$ $34.08$ $34.31$ $0.23$ $0.67$ $43$ $69.89$ $70.62$ $0.73$ $1.04$ $33.97$ $34.08$	29	66.82	66.85	0.03	0.04	33.76	33, 80	0.04	0.12	
3030.3030.3030.32 $0.32$ $0.76$ $0.711$ $0.31.75$ $0.512$ $0.512$ $0.764$ 31 $67.64$ $67.98$ $0.34$ $0.50$ $34.00$ $33.99$ $-0.01$ $-0.02$ 32 $68.27$ $68.48$ $0.21$ $0.31$ $33.60$ $33.91$ $0.31$ $0.93$ 33 $69.50$ $70.03$ $0.53$ $0.76$ $33.13$ $33.54$ $0.41$ $1.24$ 34 $67.69$ $67.83$ $0.14$ $0.20$ $33.38$ $33.29$ $-0.09$ $-0.27$ 35 $68.39$ $68.95$ $0.56$ $0.82$ $33.48$ $33.79$ $0.31$ $0.93$ 36 $69.70$ $69.23$ $-0.47$ $-0.67$ $33.15$ $33.16$ $0.01$ $0.02$ 37 $68.41$ $67.94$ $-0.47$ $-0.68$ $34.10$ $33.92$ $-0.19$ $-0.54$ 38 $69.36$ $69.24$ $-0.12$ $-0.17$ $33.85$ $33.57$ $-0.28$ $-0.83$ 39 $69.93$ $68.94$ $-0.99$ $-1.42$ $35.28$ $34.80$ $-0.48$ $-1.36$ 40 $68.43$ $67.63$ $-0.80$ $-1.17$ $34.03$ $34.25$ $0.22$ $0.64$ 41 $68.56$ $67.88$ $-0.68$ $-0.99$ $34.70$ $34.75$ $0.31$ $0.89$ 42 $69.94$ $70.12$ $0.18$ $0.26$ $34.08$ $34.31$ $0.23$ $0.67$ 43 $69.89$ $70.62$ $0.73$ $1.04$ $33.97$ $34.08$	30	69.38	69.90	0.52	0.75	34 11	33 79	-0.32	-0.94	
3161.0161.0161.0161.0161.0161.0161.0161.0132 $68.27$ $68.48$ $0.21$ $0.31$ $0.31$ $0.31$ $0.93$ 33 $69.50$ $70.03$ $0.53$ $0.76$ $33.13$ $33.54$ $0.41$ $1.24$ 34 $67.69$ $67.83$ $0.14$ $0.20$ $33.38$ $33.29$ $-0.09$ $-0.27$ 35 $68.39$ $68.95$ $0.56$ $0.82$ $33.48$ $33.79$ $0.31$ $0.93$ 36 $69.70$ $69.23$ $-0.47$ $-0.67$ $33.15$ $33.16$ $0.01$ $0.02$ 37 $68.41$ $67.94$ $-0.47$ $-0.68$ $34.10$ $33.92$ $-0.19$ $-0.54$ 38 $69.36$ $69.24$ $-0.12$ $-0.17$ $33.85$ $33.57$ $-0.28$ $-0.83$ 39 $69.36$ $69.24$ $-0.99$ $-1.42$ $35.28$ $34.80$ $-0.48$ $-1.36$ 40 $68.43$ $67.63$ $-0.80$ $-1.17$ $34.03$ $34.25$ $0.22$ $0.64$ 41 $68.56$ $67.88$ $-0.68$ $-0.99$ $34.70$ $34.75$ $0.05$ $0.14$ 42 $69.94$ $70.12$ $0.18$ $0.26$ $34.08$ $34.31$ $0.23$ $0.67$ 43 $69.89$ $70.62$ $0.73$ $1.04$ $33.97$ $34.08$ $0.11$ $0.31$ 44 $69.56$ $69.12$ $-0.44$ $-0.63$ $34.44$ $34.75$ $0.31$ $0.89$ 45 $68.42$ </td <td>31</td> <td>67.64</td> <td>67.98</td> <td>0.34</td> <td>0.50</td> <td>34.00</td> <td>33, 99</td> <td>-0.01</td> <td>-0.02</td>	31	67.64	67.98	0.34	0.50	34.00	33, 99	-0.01	-0.02	
33 $69.50$ $70.03$ $0.53$ $0.76$ $33.13$ $33.54$ $0.41$ $1.24$ $34$ $67.69$ $67.83$ $0.14$ $0.20$ $33.38$ $33.29$ $-0.09$ $-0.27$ $35$ $68.39$ $68.95$ $0.56$ $0.82$ $33.48$ $33.79$ $0.31$ $0.93$ $36$ $69.70$ $69.23$ $-0.47$ $-0.67$ $33.15$ $33.16$ $0.01$ $0.02$ $37$ $68.41$ $67.94$ $-0.47$ $-0.68$ $34.10$ $33.92$ $-0.19$ $-0.54$ $38$ $69.36$ $69.24$ $-0.12$ $-0.17$ $33.85$ $33.57$ $-0.28$ $-0.83$ $39$ $69.93$ $68.94$ $-0.99$ $-1.42$ $35.28$ $34.80$ $-0.48$ $-1.36$ $40$ $68.43$ $67.63$ $-0.80$ $-1.17$ $34.03$ $34.25$ $0.22$ $0.64$ $41$ $68.56$ $67.88$ $-0.68$ $-0.99$ $34.70$ $34.75$ $0.05$ $0.14$ $42$ $69.94$ $70.12$ $0.18$ $0.26$ $34.08$ $34.31$ $0.23$ $0.67$ $43$ $69.89$ $70.62$ $0.73$ $1.04$ $33.97$ $34.08$ $0.11$ $0.31$ $44$ $69.56$ $69.12$ $-0.44$ $-0.63$ $34.44$ $34.75$ $0.31$ $0.89$ $45$ $68.42$ $69.49$ $1.07$ $1.57$ $33.64$ $33.82$ $0.18$ $0.55$ $46$ $70.41$ $70.69$ $0.28$ $0.39$ $33.49$ $33.15$ $-$	32	68 27	68 48	0.21	0.31	33,60	33 91	0.31	0.93	
3467.6967.830.140.2033.3833.29 $-0.09$ $-0.27$ 3568.3968.950.560.8233.4833.790.310.933669.7069.23 $-0.47$ $-0.67$ 33.1533.160.010.023768.4167.94 $-0.47$ $-0.68$ 34.1033.92 $-0.19$ $-0.54$ 3869.3669.24 $-0.12$ $-0.17$ 33.8533.57 $-0.28$ $-0.83$ 3969.9368.94 $-0.99$ $-1.42$ 35.2834.80 $-0.48$ $-1.36$ 4068.4367.63 $-0.80$ $-1.17$ 34.0334.25 $0.22$ $0.64$ 4168.5667.88 $-0.68$ $-0.99$ 34.7034.75 $0.05$ $0.14$ 4269.9470.12 $0.18$ $0.26$ 34.0834.31 $0.23$ $0.67$ 4369.8970.62 $0.73$ $1.04$ 33.9734.08 $0.11$ $0.31$ 4469.5669.12 $-0.44$ $-0.63$ 34.4434.75 $0.31$ $0.89$ 4568.4269.49 $1.07$ $1.57$ $33.64$ $33.82$ $0.18$ $0.55$ 4670.4170.69 $0.28$ $0.39$ $33.49$ $33.15$ $-0.34$ $-1.02$ 4769.8969.40 $-0.49$ $-0.70$ $34.48$ $34.03$ $-0.45$ $-1.31$ 4870.5770.94 $0.37$ $0.53$ $33.64$ $33.94$	33	69.50	70, 03	0.53	0. 76	33, 13	33, 54	0.41	1. 24	
35 $68.39$ $68.95$ $0.56$ $0.82$ $33.48$ $33.79$ $0.31$ $0.93$ $36$ $69.70$ $69.23$ $-0.47$ $-0.67$ $33.15$ $33.16$ $0.01$ $0.02$ $37$ $68.41$ $67.94$ $-0.47$ $-0.67$ $33.15$ $33.16$ $0.01$ $0.02$ $38$ $69.36$ $69.24$ $-0.17$ $-0.68$ $34.10$ $33.92$ $-0.19$ $-0.54$ $38$ $69.36$ $69.24$ $-0.12$ $-0.17$ $33.85$ $33.57$ $-0.28$ $-0.83$ $39$ $69.93$ $68.94$ $-0.99$ $-1.42$ $35.28$ $34.80$ $-0.48$ $-1.36$ $40$ $68.43$ $67.63$ $-0.80$ $-1.17$ $34.03$ $34.25$ $0.22$ $0.64$ $41$ $68.56$ $67.88$ $-0.68$ $-0.99$ $34.70$ $34.75$ $0.05$ $0.14$ $42$ $69.94$ $70.12$ $0.18$ $0.26$ $34.08$ $34.31$ $0.23$ $0.67$ $43$ $69.89$ $70.62$ $0.73$ $1.04$ $33.97$ $34.08$ $0.11$ $0.31$ $44$ $69.56$ $69.12$ $-0.44$ $-0.63$ $34.44$ $34.75$ $0.31$ $0.89$ $45$ $68.42$ $69.49$ $1.07$ $1.57$ $33.64$ $33.82$ $0.18$ $0.55$ $46$ $70.41$ $70.69$ $0.28$ $0.39$ $33.49$ $33.15$ $-0.34$ $-1.02$ $47$ $69.89$ $69.40$ $-0.49$ $-0.70$ $34.48$ $34.03$ <t< td=""><td>34</td><td>67.69</td><td>67.83</td><td>0.14</td><td>0. 20</td><td>33, 38</td><td>33, 29</td><td>-0.09</td><td>-0.27</td></t<>	34	67.69	67.83	0.14	0. 20	33, 38	33, 29	-0.09	-0.27	
36 $60.00$ $60.00$ $60.00$ $60.00$ $60.00$ $60.00$ $60.00$ $60.00$ $60.00$ $36$ $69.70$ $69.23$ $-0.47$ $-0.67$ $33.15$ $33.16$ $0.01$ $0.02$ $37$ $68.41$ $67.94$ $-0.47$ $-0.68$ $34.10$ $33.92$ $-0.19$ $-0.54$ $38$ $69.36$ $69.24$ $-0.12$ $-0.17$ $33.85$ $33.57$ $-0.28$ $-0.83$ $39$ $69.93$ $68.94$ $-0.99$ $-1.42$ $35.28$ $34.80$ $-0.48$ $-1.36$ $40$ $68.43$ $67.63$ $-0.80$ $-1.17$ $34.03$ $34.25$ $0.22$ $0.64$ $41$ $68.56$ $67.88$ $-0.68$ $-0.99$ $34.70$ $34.75$ $0.05$ $0.14$ $42$ $69.94$ $70.12$ $0.18$ $0.26$ $34.08$ $34.31$ $0.23$ $0.67$ $43$ $69.89$ $70.62$ $0.73$ $1.04$ $33.97$ $34.08$ $0.11$ $0.31$ $44$ $69.56$ $69.12$ $-0.44$ $-0.63$ $34.44$ $34.75$ $0.31$ $0.89$ $45$ $68.42$ $69.49$ $1.07$ $1.57$ $33.64$ $33.82$ $0.18$ $0.55$ $46$ $70.41$ $70.69$ $0.28$ $0.39$ $33.49$ $33.15$ $-0.34$ $-1.02$ $47$ $69.89$ $69.40$ $-0.49$ $-0.70$ $34.48$ $34.03$ $-0.45$ $-1.31$ $48$ $70.57$ $70.94$ $0.37$ $0.53$ $33.64$ <td>35</td> <td>68.39</td> <td>68, 95</td> <td>0.56</td> <td>0. 82</td> <td>33, 48</td> <td>33, 79</td> <td>0.31</td> <td>0. 93</td>	35	68.39	68, 95	0.56	0. 82	33, 48	33, 79	0.31	0. 93	
37 $68.41$ $67.94$ $-0.47$ $-0.68$ $34.10$ $33.92$ $-0.19$ $-0.54$ $38$ $69.36$ $69.24$ $-0.12$ $-0.17$ $33.85$ $33.57$ $-0.28$ $-0.83$ $39$ $69.93$ $68.94$ $-0.99$ $-1.42$ $35.28$ $34.80$ $-0.48$ $-1.36$ $40$ $68.43$ $67.63$ $-0.80$ $-1.17$ $34.03$ $34.25$ $0.22$ $0.64$ $41$ $68.56$ $67.88$ $-0.68$ $-0.99$ $34.70$ $34.75$ $0.05$ $0.14$ $42$ $69.94$ $70.12$ $0.18$ $0.26$ $34.08$ $34.31$ $0.23$ $0.67$ $43$ $69.89$ $70.62$ $0.73$ $1.04$ $33.97$ $34.08$ $0.11$ $0.31$ $44$ $69.56$ $69.12$ $-0.44$ $-0.63$ $34.44$ $34.75$ $0.31$ $0.89$ $45$ $68.42$ $69.49$ $1.07$ $1.57$ $33.64$ $33.82$ $0.18$ $0.55$ $46$ $70.41$ $70.69$ $0.28$ $0.39$ $33.49$ $33.15$ $-0.34$ $-1.02$ $47$ $69.89$ $69.40$ $-0.49$ $-0.70$ $34.48$ $34.03$ $-0.45$ $-1.31$ $48$ $70.57$ $70.94$ $0.37$ $0.53$ $33.64$ $33.94$ $0.30$ $0.89$	36	69.70	69.23	-0.47	-0.67	33, 15	33, 16	0.01	0.02	
3869.3669.24 $-0.12$ $-0.17$ 33.8533.57 $-0.28$ $-0.83$ 3969.9368.94 $-0.99$ $-1.42$ 35.2834.80 $-0.48$ $-1.36$ 4068.4367.63 $-0.80$ $-1.17$ 34.0334.25 $0.22$ $0.64$ 4168.5667.88 $-0.68$ $-0.99$ 34.7034.75 $0.05$ $0.14$ 4269.9470.12 $0.18$ $0.26$ 34.0834.31 $0.23$ $0.67$ 4369.8970.62 $0.73$ $1.04$ $33.97$ $34.08$ $0.11$ $0.31$ 4469.5669.12 $-0.44$ $-0.63$ $34.44$ $34.75$ $0.31$ $0.89$ 4568.4269.49 $1.07$ $1.57$ $33.64$ $33.82$ $0.18$ $0.55$ 4670.4170.69 $0.28$ $0.39$ $33.49$ $33.15$ $-0.34$ $-1.02$ 4769.8969.40 $-0.49$ $-0.70$ $34.48$ $34.03$ $-0.45$ $-1.31$ 4870.5770.94 $0.37$ $0.53$ $33.64$ $33.94$ $0.30$ $0.89$	37	68.41	67.94	-0.47	-0.68	34.10	33, 92	-0.19	-0.54	
39 $69.93$ $68.94$ $-0.99$ $-1.42$ $35.28$ $34.80$ $-0.48$ $-1.36$ $40$ $68.43$ $67.63$ $-0.80$ $-1.17$ $34.03$ $34.25$ $0.22$ $0.64$ $41$ $68.56$ $67.88$ $-0.68$ $-0.99$ $34.70$ $34.75$ $0.05$ $0.14$ $42$ $69.94$ $70.12$ $0.18$ $0.26$ $34.08$ $34.31$ $0.23$ $0.67$ $43$ $69.89$ $70.62$ $0.73$ $1.04$ $33.97$ $34.08$ $0.11$ $0.31$ $44$ $69.56$ $69.12$ $-0.44$ $-0.63$ $34.44$ $34.75$ $0.31$ $0.89$ $45$ $68.42$ $69.49$ $1.07$ $1.57$ $33.64$ $33.82$ $0.18$ $0.55$ $46$ $70.41$ $70.69$ $0.28$ $0.39$ $33.49$ $33.15$ $-0.34$ $-1.02$ $47$ $69.89$ $69.40$ $-0.49$ $-0.70$ $34.48$ $34.03$ $-0.45$ $-1.31$ $48$ $70.57$ $70.94$ $0.37$ $0.53$ $33.64$ $33.94$ $0.30$ $0.89$	38	69.36	69.24	-0.12	-0.17	33, 85	33. 57	-0.28	-0.83	
40 $68.43$ $67.63$ $-0.80$ $-1.17$ $34.03$ $34.25$ $0.22$ $0.64$ $41$ $68.56$ $67.88$ $-0.68$ $-0.99$ $34.70$ $34.75$ $0.05$ $0.14$ $42$ $69.94$ $70.12$ $0.18$ $0.26$ $34.08$ $34.31$ $0.23$ $0.67$ $43$ $69.89$ $70.62$ $0.73$ $1.04$ $33.97$ $34.08$ $0.11$ $0.31$ $44$ $69.56$ $69.12$ $-0.44$ $-0.63$ $34.44$ $34.75$ $0.31$ $0.89$ $45$ $68.42$ $69.49$ $1.07$ $1.57$ $33.64$ $33.82$ $0.18$ $0.55$ $46$ $70.41$ $70.69$ $0.28$ $0.39$ $33.49$ $33.15$ $-0.34$ $-1.02$ $47$ $69.89$ $69.40$ $-0.49$ $-0.70$ $34.48$ $34.03$ $-0.45$ $-1.31$ $48$ $70.57$ $70.94$ $0.37$ $0.53$ $33.64$ $33.94$ $0.30$ $0.89$	39	69, 93	68.94	-0.99	-1.42	35.28	34.80	-0.48	-1.36	
10 $00.10$ $01.00$ $01.00$ $01.00$ $01.11$ $01.00$ $01.20$ $01.21$ $01.01$ $41$ $68.56$ $67.88$ $-0.68$ $-0.99$ $34.70$ $34.75$ $0.05$ $0.14$ $42$ $69.94$ $70.12$ $0.18$ $0.26$ $34.08$ $34.31$ $0.23$ $0.67$ $43$ $69.89$ $70.62$ $0.73$ $1.04$ $33.97$ $34.08$ $0.11$ $0.31$ $44$ $69.56$ $69.12$ $-0.44$ $-0.63$ $34.44$ $34.75$ $0.31$ $0.89$ $45$ $68.42$ $69.49$ $1.07$ $1.57$ $33.64$ $33.82$ $0.18$ $0.55$ $46$ $70.41$ $70.69$ $0.28$ $0.39$ $33.49$ $33.15$ $-0.34$ $-1.02$ $47$ $69.89$ $69.40$ $-0.49$ $-0.70$ $34.48$ $34.03$ $-0.45$ $-1.31$ $48$ $70.57$ $70.94$ $0.37$ $0.53$ $33.64$ $33.94$ $0.30$ $0.89$	40	68. 43	67.63	-0.80	-1.17	34. 03	34, 25	0.22	0.64	
11 $0.100$ $0.100$ $0.100$ $0.100$ $0.110$ $0.100$ $0.100$ $0.111$ $42$ $69.94$ $70.12$ $0.18$ $0.26$ $34.08$ $34.31$ $0.23$ $0.67$ $43$ $69.89$ $70.62$ $0.73$ $1.04$ $33.97$ $34.08$ $0.11$ $0.31$ $44$ $69.56$ $69.12$ $-0.44$ $-0.63$ $34.44$ $34.75$ $0.31$ $0.89$ $45$ $68.42$ $69.49$ $1.07$ $1.57$ $33.64$ $33.82$ $0.18$ $0.55$ $46$ $70.41$ $70.69$ $0.28$ $0.39$ $33.49$ $33.15$ $-0.34$ $-1.02$ $47$ $69.89$ $69.40$ $-0.49$ $-0.70$ $34.48$ $34.03$ $-0.45$ $-1.31$ $48$ $70.57$ $70.94$ $0.37$ $0.53$ $33.64$ $33.94$ $0.30$ $0.89$	41	68, 56	67.88	-0.68	-0.99	34.70	34, 75	0.05	0.14	
12 $10112$ $10122$ $10125$ $10125$ $10135$ $10145$ $10125$ $10145$ $43$ $69.89$ $70.62$ $0.73$ $1.04$ $33.97$ $34.08$ $0.11$ $0.31$ $44$ $69.56$ $69.12$ $-0.44$ $-0.63$ $34.44$ $34.75$ $0.31$ $0.89$ $45$ $68.42$ $69.49$ $1.07$ $1.57$ $33.64$ $33.82$ $0.18$ $0.55$ $46$ $70.41$ $70.69$ $0.28$ $0.39$ $33.49$ $33.15$ $-0.34$ $-1.02$ $47$ $69.89$ $69.40$ $-0.49$ $-0.70$ $34.48$ $34.03$ $-0.45$ $-1.31$ $48$ $70.57$ $70.94$ $0.37$ $0.53$ $33.64$ $33.94$ $0.30$ $0.89$	42	69.94	70, 12	0.18	0.26	34.08	34, 31	0. 23	0.67	
44 $69.56$ $69.12$ $-0.44$ $-0.63$ $34.44$ $34.75$ $0.31$ $0.89$ $45$ $68.42$ $69.49$ $1.07$ $1.57$ $33.64$ $33.82$ $0.18$ $0.55$ $46$ $70.41$ $70.69$ $0.28$ $0.39$ $33.49$ $33.15$ $-0.34$ $-1.02$ $47$ $69.89$ $69.40$ $-0.49$ $-0.70$ $34.48$ $34.03$ $-0.45$ $-1.31$ $48$ $70.57$ $70.94$ $0.37$ $0.53$ $33.64$ $33.94$ $0.30$ $0.89$	43	69.89	70, 62	0.73	1.04	33.97	34, 08	0.11	0.31	
45       68.42       69.49       1.07       1.57       33.64       33.82       0.18       0.55         46       70.41       70.69       0.28       0.39       33.49       33.15       -0.34       -1.02         47       69.89       69.40       -0.49       -0.70       34.48       34.03       -0.45       -1.31         48       70.57       70.94       0.37       0.53       33.64       33.94       0.30       0.89	44	69.56	69, 12	-0.44	-0.63	34.44	34, 75	0.31	0.89	
46 $70.41$ $70.69$ $0.28$ $0.39$ $33.49$ $33.15$ $-0.34$ $-1.02$ $47$ $69.89$ $69.40$ $-0.49$ $-0.70$ $34.48$ $34.03$ $-0.45$ $-1.31$ $48$ $70.57$ $70.94$ $0.37$ $0.53$ $33.64$ $33.94$ $0.30$ $0.89$	45	68. 42	69.49	1.07	1. 57	33 64	33, 82	0.18	0. 55	
47       69.89       69.40       -0.49       -0.70       34.48       34.03       -0.45       -1.31         48       70.57       70.94       0.37       0.53       33.64       33.94       0.30       0.89	46	70, 41	70.69	0. 28	0.39	33 49	33, 15	-0.34	-1 02	
48         70.57         70.94         0.37         0.53         33.64         33.94         0.30         0.89	47	69.89	69.40	-0.49	-0.70	34 48	34, 03	-0.45	-1 31	
	48	70.57	70.94	0.37	0.53	33.64	33.94	0.30	0.89	

 
 Table 1
 Comparison between practical measure values and near infrared prediction values of holocellulose and lignin

δ:绝对偏差;δ(%):相对偏差

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# Determination of Holocellulose and Lignin Content in Chinese Fir by Near Infrared Spectroscopy

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**Abstract** The contents of holocellulose and lignin of wood are important determinants of the pulping quality of wood. The determination of holocellulose and lignin contents using traditional chemical methods is a costly and time-consuming process. Near infrared reflectance (NIR) analysis offers a fast, nondestructive testing and low cost alternative for prediction of wood quality. In the present article, the total amounts of holocellulose and lignin contents of 48 samples were analyzed according to standard wetchemical method. All samples were milled using a Standard Wiley knife mill with a 2 mm screen. The 2 mm material was sieved with a 40-60 mesh sieve. Then, near infrared (NIR) spectra were collected in diffuse reflectance from samples of meal contained in a spinning cup by an analytical spectral devices (ASD) Lab Spec at wavelengths between 350 nm and 2 500 nm. The raw spectra were pretreated by the second derivative and smoothing, then the NIR model was built using partial least-squares statistical analysis and full cross validation. The coefficients of correlation (r) of calibration and validation for holocellulose were 0.96 and 0.93, respectively; the standard error of calibration (SEC) and the standard error of prediction (SEP) were 0.39 and 0.50, respectively. For lignin, the values for r of calibration and validation were 0.99 and 0.90, while the SEC and SEP were 0.10 and 0.28, respectively. It was concluded that NIR analysis is a reliable, fast and nondestructive testing predictor of holocellulose and lignin content of wood in Chinese fir.

Keywords Near infrared spectroscopic(NIR); Holocellulose; Lignin