Bio-oil fuels production from microalgae after heterotrophic growth

(藻类异养转化制备生物油燃料技术)

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1. Materials (实验材料)

- **photoautotrophic *Chlorella prototheco*ides**
  自养小球藻 **(AC)**

- **heterotrophic *Chlorella prototheco*ides**
  异养小球藻 **(HC)**

- ***Microcystis***
  微囊藻 (一种水华藻类）

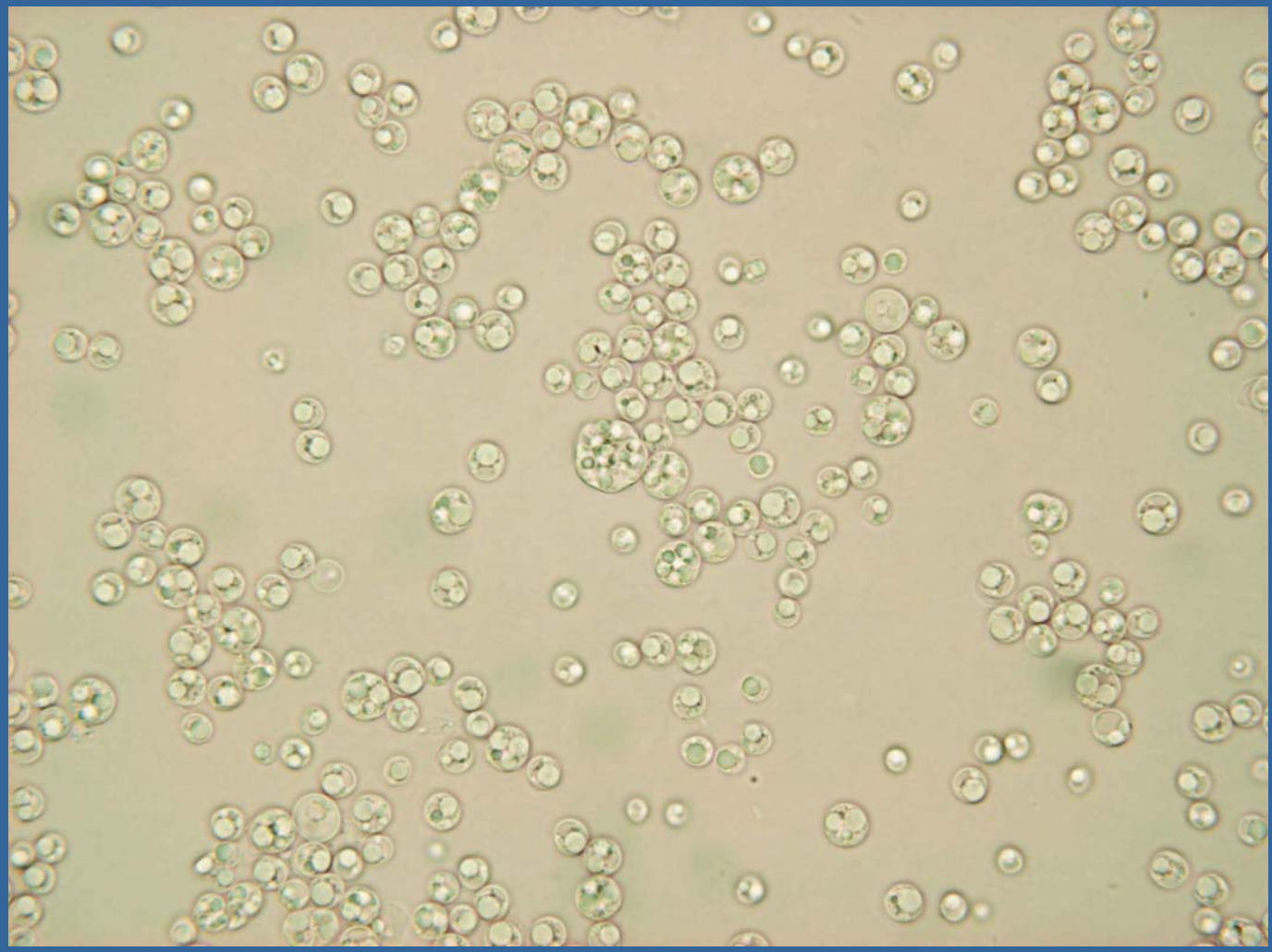


Fig. 1 The shape of *Chlorella protothecoids* under light microscope (10×40). The diameter of cells is about 3-12 μm.

（图1 小球藻细胞在光学显微镜下放大400倍图）

photoautotrophic heterotrophic

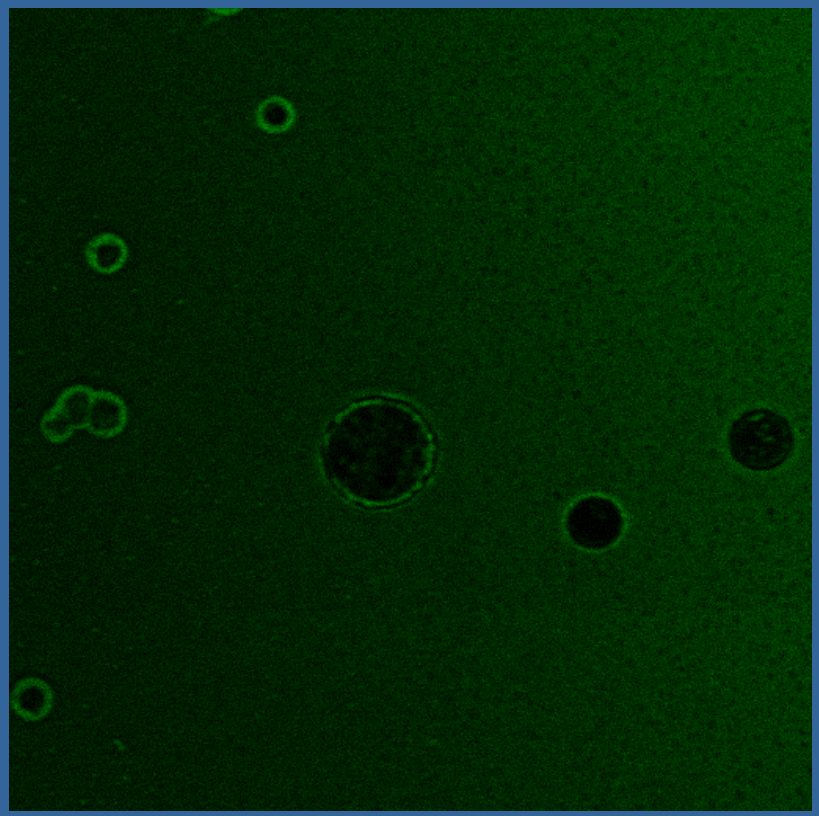
(in liquid medium)

photoautotrophic heterotrophic

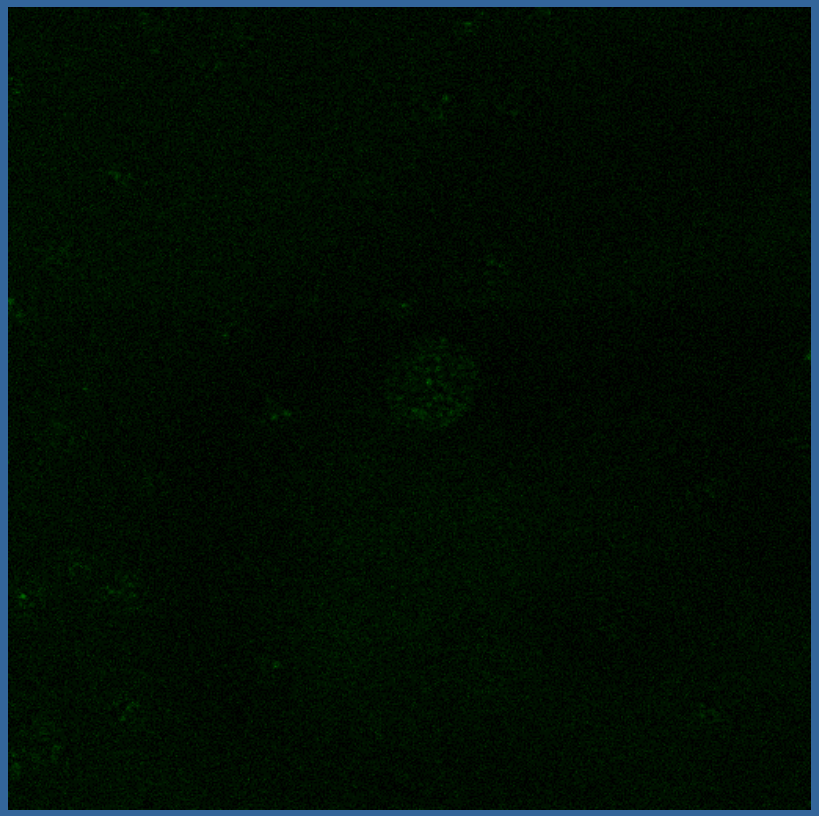
(on agar plates)

Fig. 2 Cells of Chlorella prototheсoids under photoautotrophic and heterotrophic culture conditions.

（图2 自养和异养条件下的小球藻细胞）



AC



HC

Fig. 3 Cells of photoautotrophic *Chlorella protothecoids* (AC) and heterotrophic *Chlorella protothecoids* (HC) under confocal laser scanning microscope.

（图3 自养和异养小球藻细胞在激光共聚焦扫描显微镜下示意图）

Table 1

The contents of main chemical components in cells of AC and HC.

（表1　AC、HC细胞主要生化成分含量）

Strain	Protein (%)	Lipid (%)	Carbohydrate (%)	Ash (%)	Moisture (%)	Others (%)
AC	52.64	14.57	10.62	7.38	8.74	6.05
HC	10.28	54.70	15.19	7.24	5.40	7.19

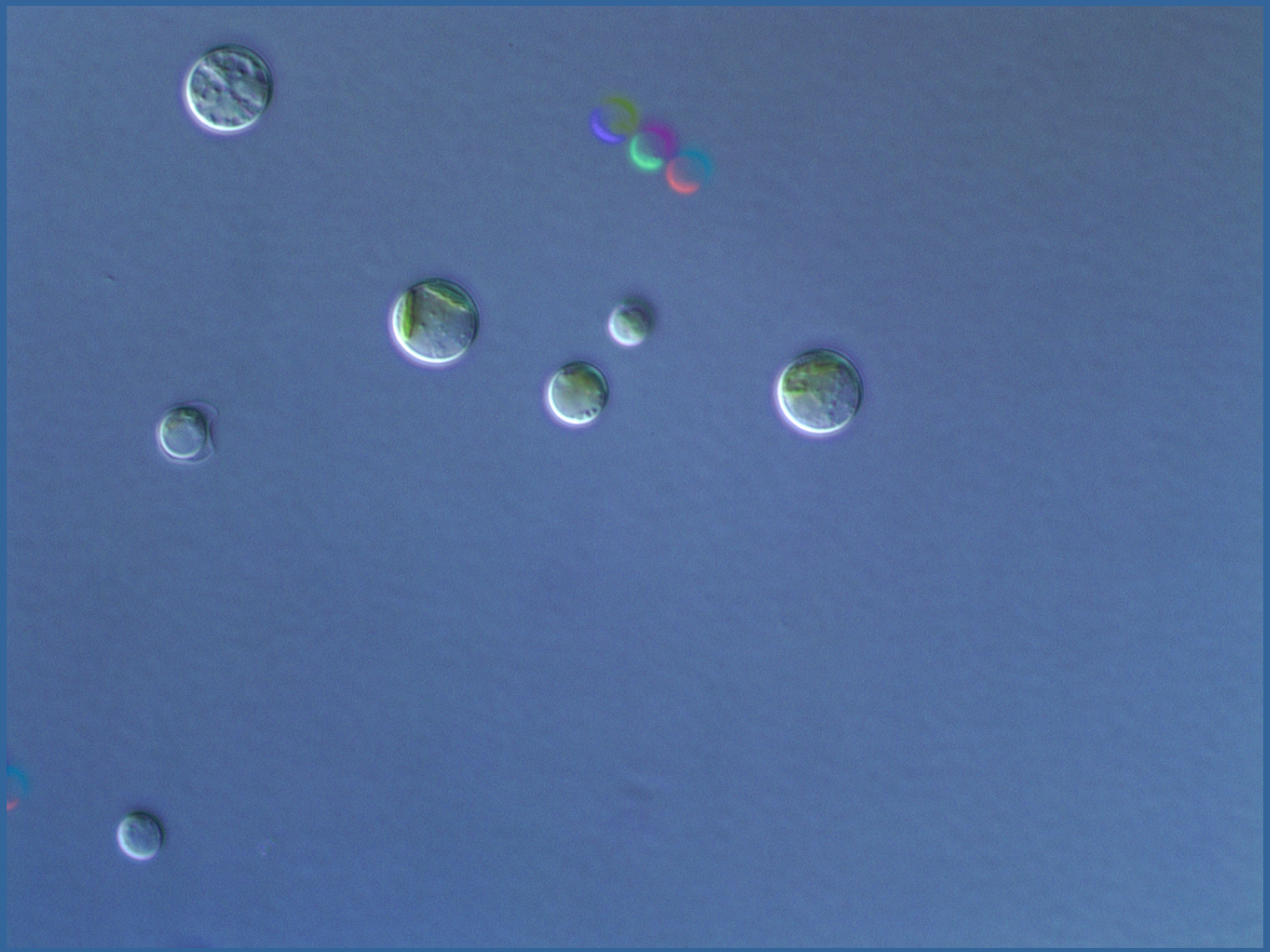


Fig. 4 Cells of AC under differential interference microscopy.

（图4　微分干涉显微镜下的自养小球藻细胞）

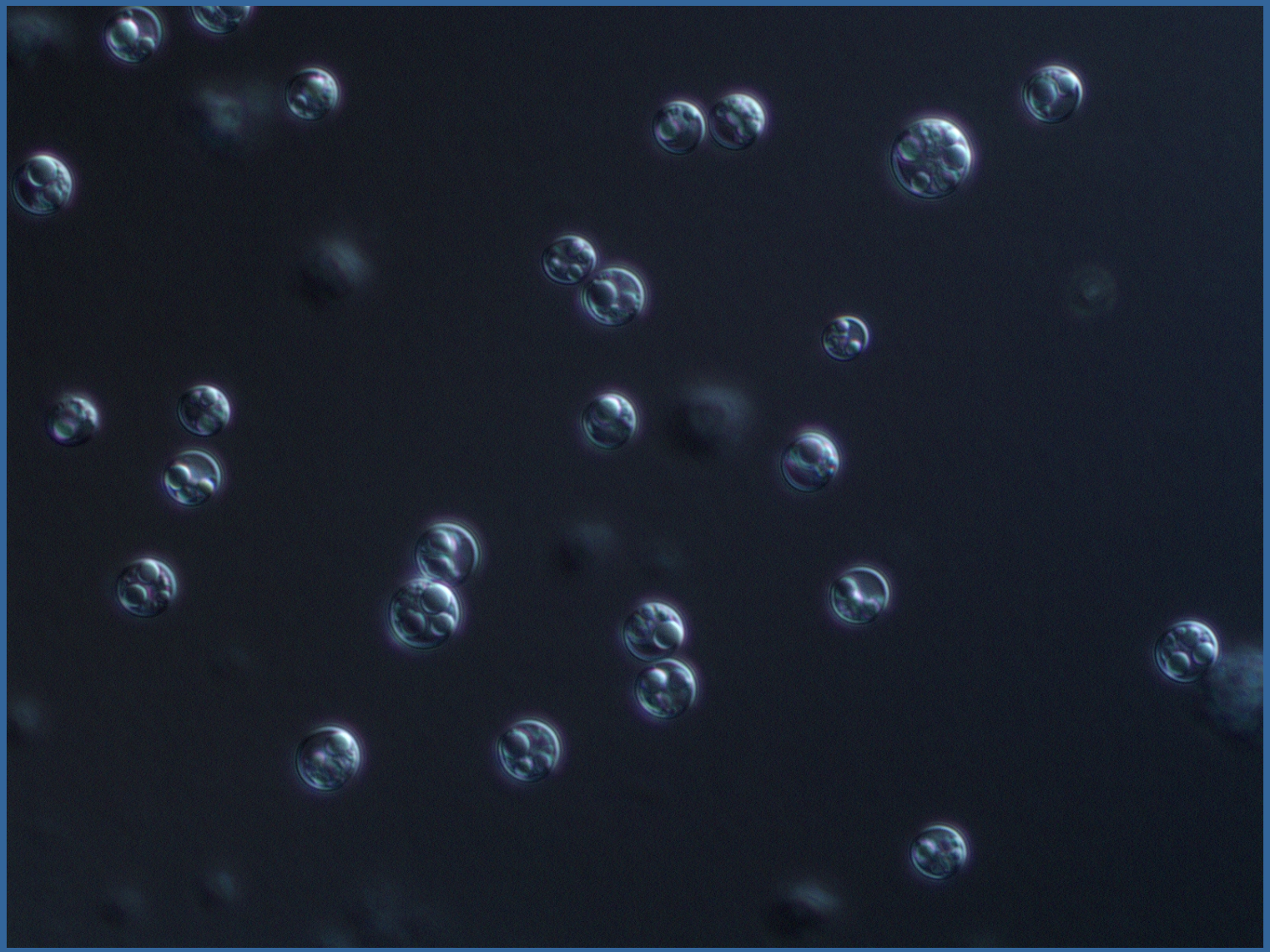
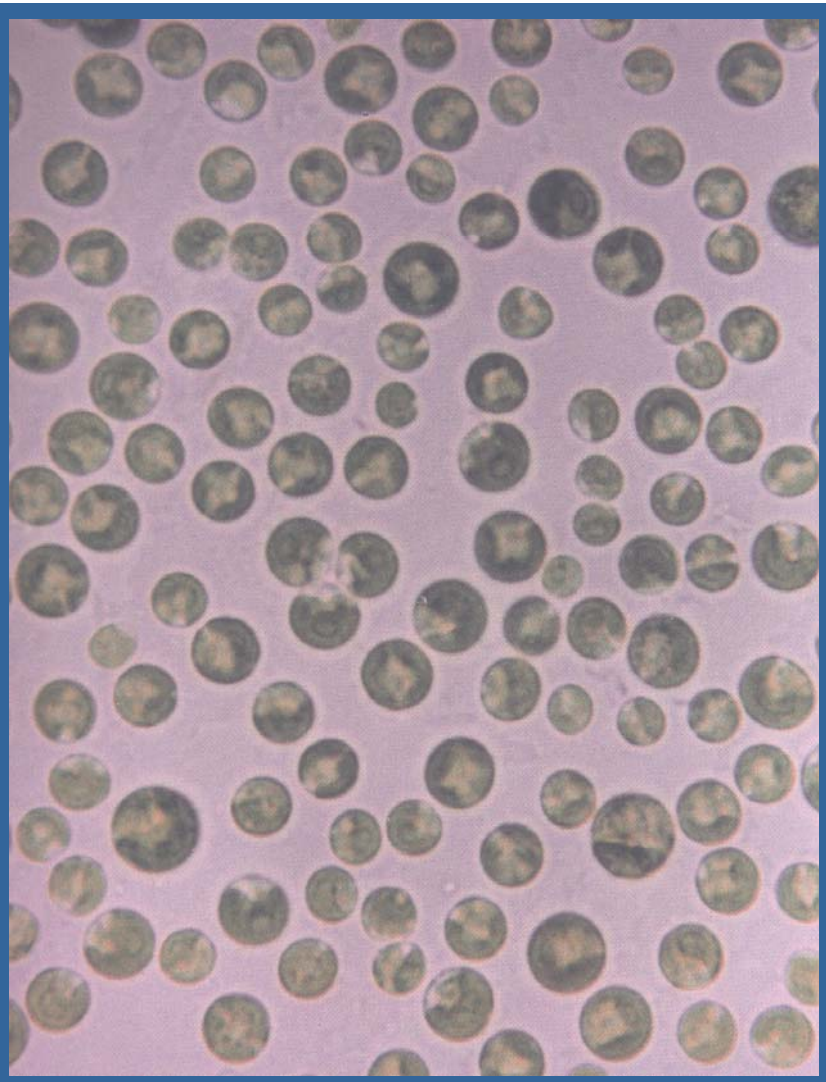
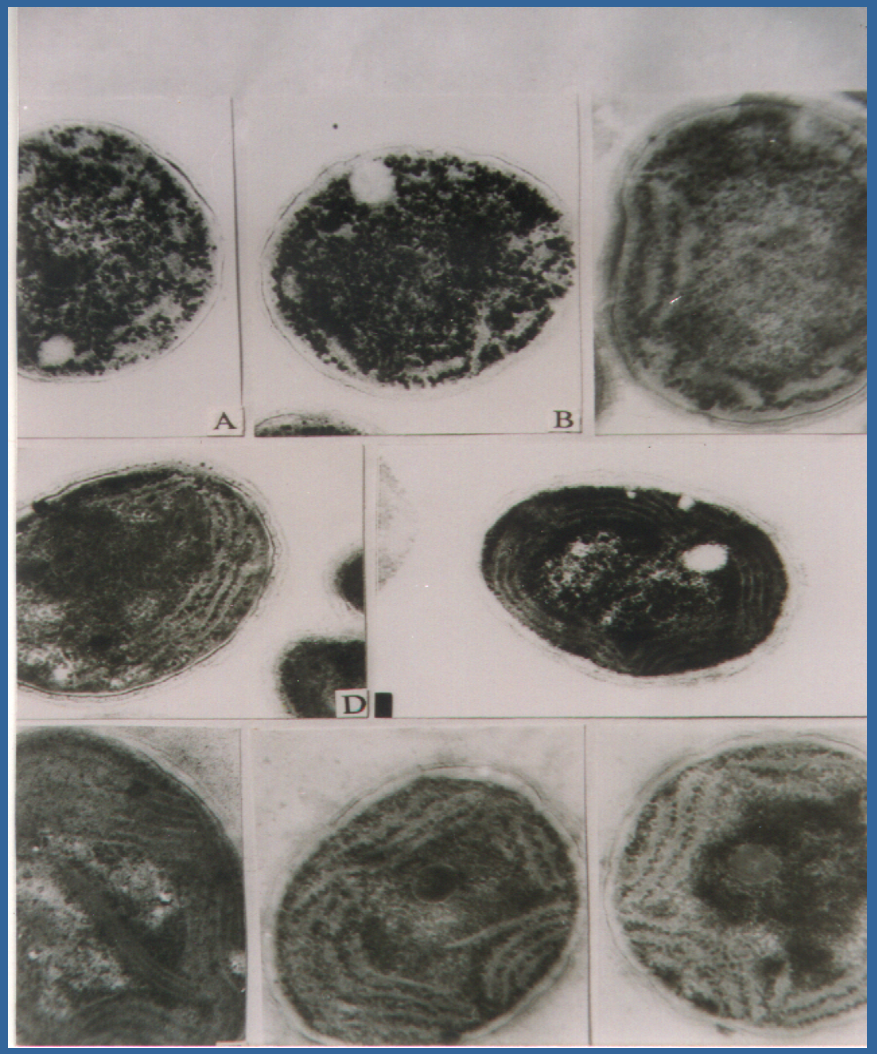


Fig. 5　Cells of HC under differential interference microscopy.

（图5　微分干涉显微镜下的HC细胞，可见细胞内充满脂肪泡）





a b

Fig. 6 *C. protothecoids* cells under light microscope (a) and electron microscope (b).

（图6　光学显微镜(a)和电镜下(b)小球藻细胞结构图）

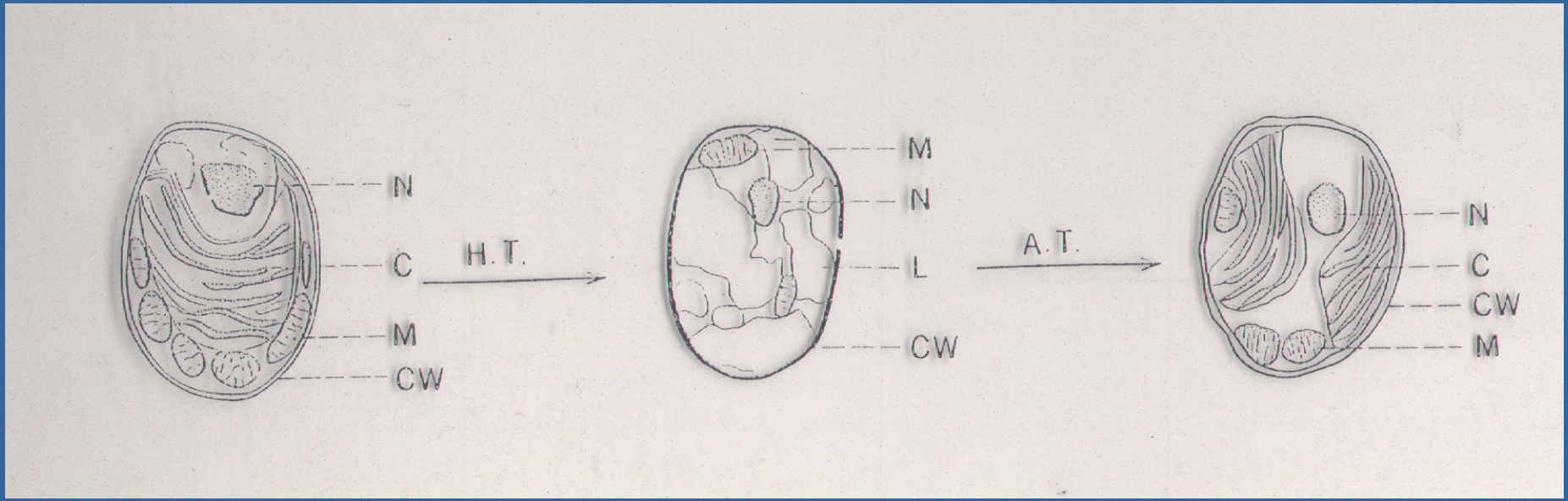


Fig. 7 Differences in cell organization between HC and AC cells.

（图7 小球藻异养和自养转化细胞结构变化示意图）

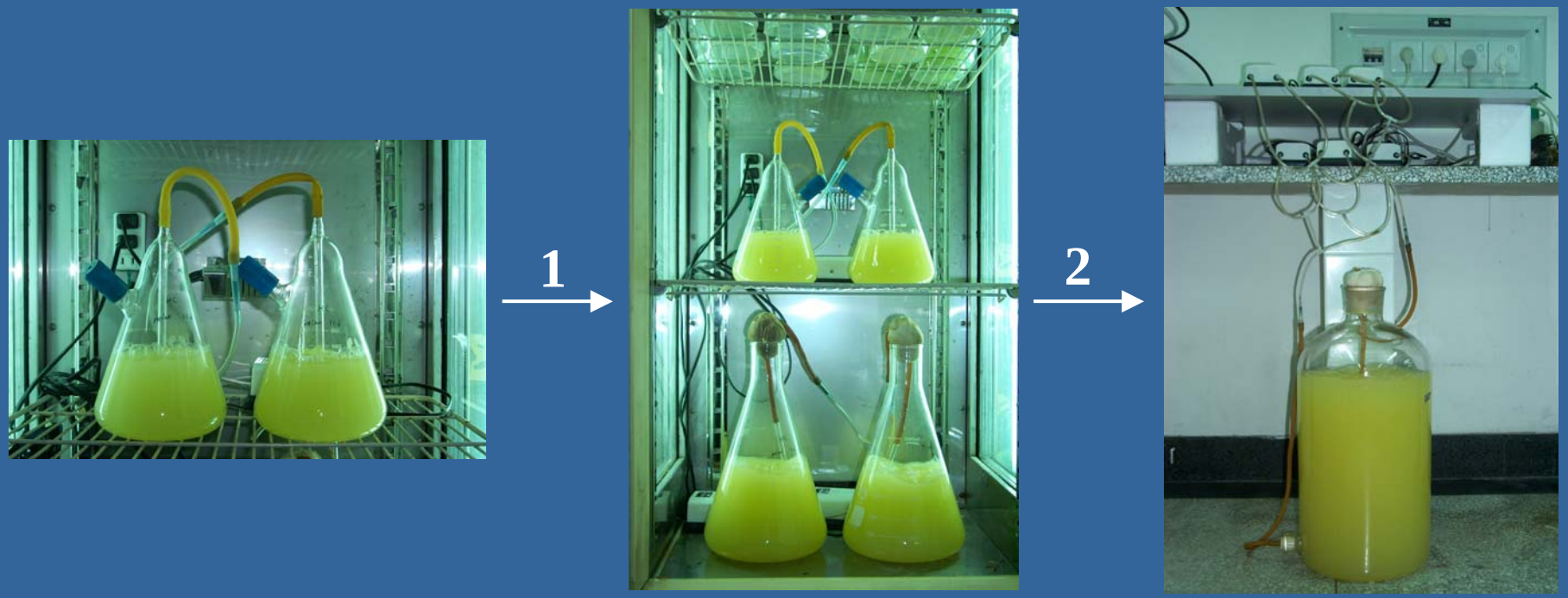
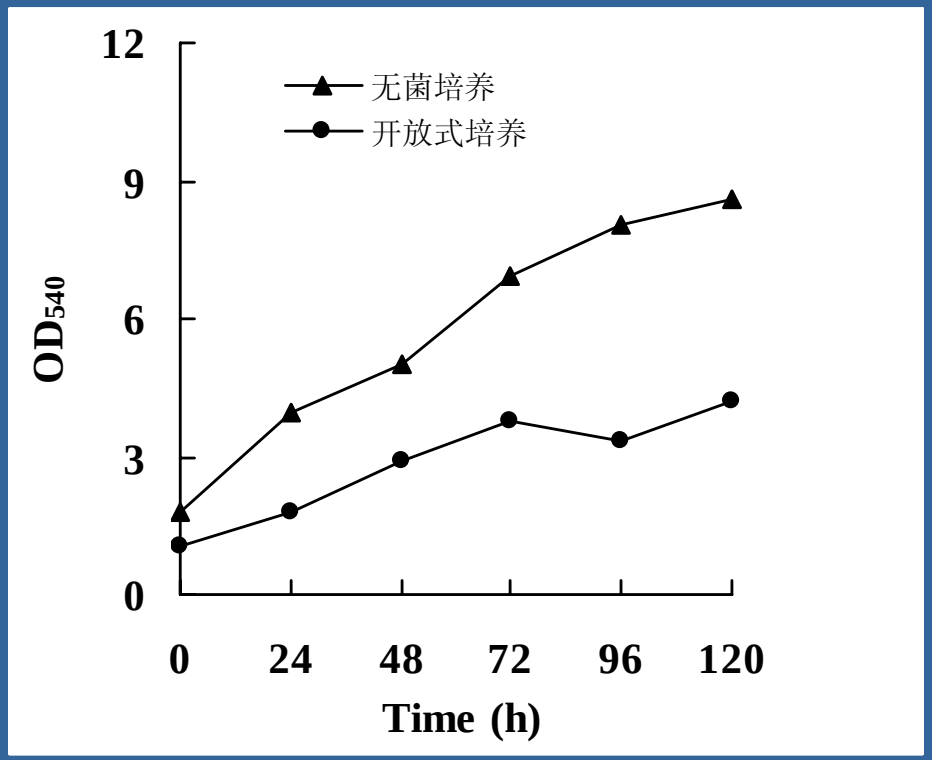


Fig. 8 The culture process of the HC cells by “Two Step” method.

（图8 两步法半无菌的细胞培养流程示意图）

Fig. 8 The culture process of the HC cells by "Two Step" method.



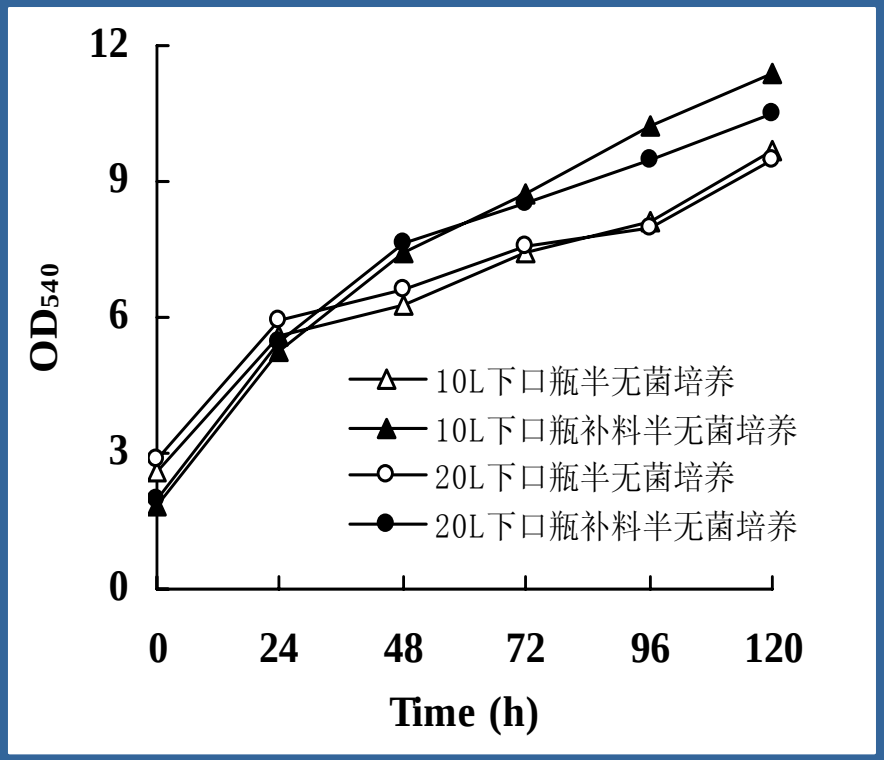


Fig. 9 Comparison of the HC cell growth under axenic, half-axenic and no-axenic culture conditions.

（图9 异养小球藻在无菌、半无菌和开放条件下培养的生长情况比较。）

2. Fast pyrolysis of microalgae
(藻类的快速热解)

Pyrolysis system: the fluid bed reactor (Fig. 7)
(热解装置：流化床快速热解（图7）)

Pyrolysis conditions (热解条件):

Temperature (温度)：500℃

heating rate (升温速率)：600 ℃/s

vapor residence time (产物停留时间)：2-3 s

biomass-feeding rate (进料速度)：4g/min

particle size (样品颗粒大小) < 0.5 mm

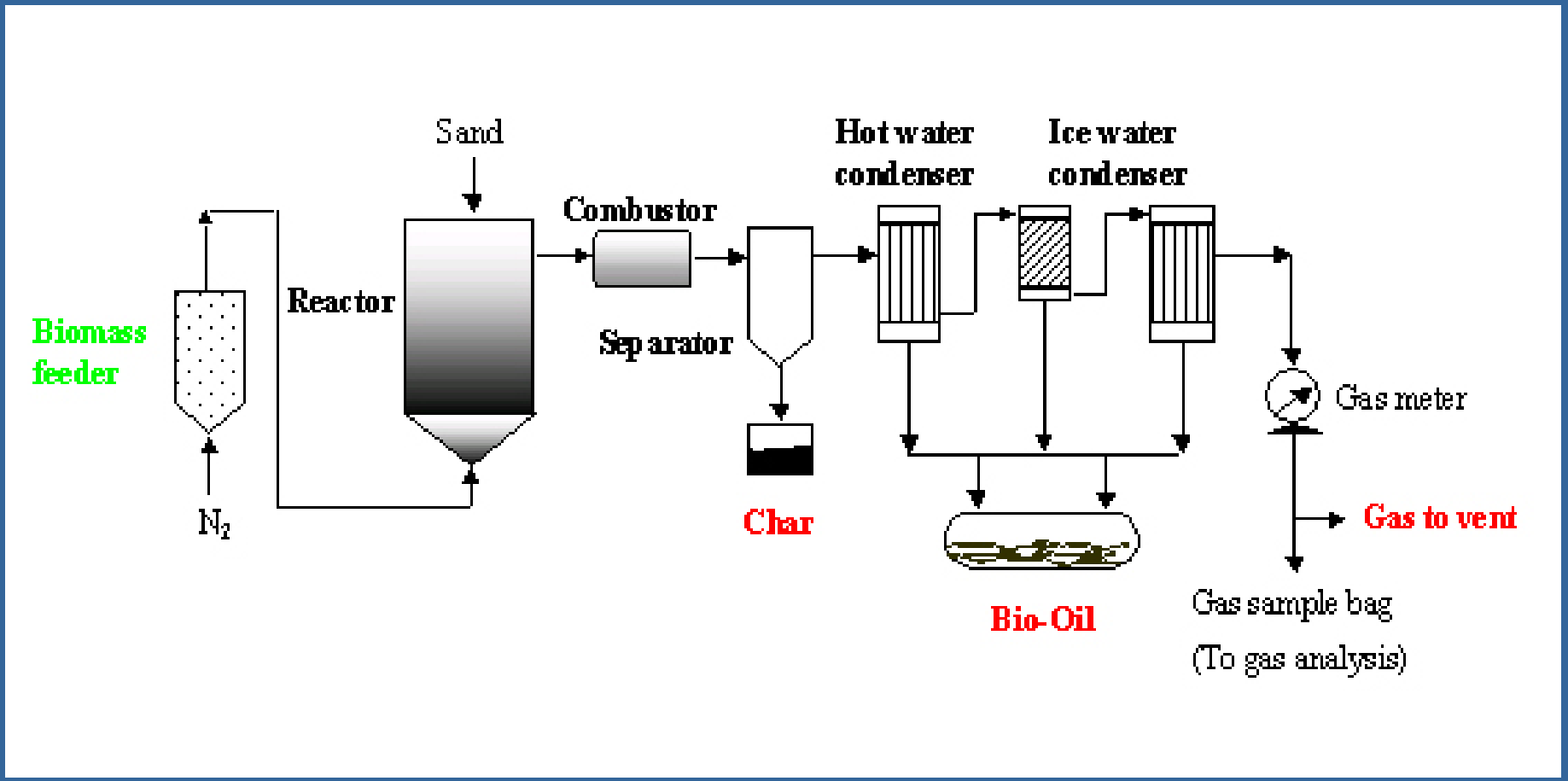


Fig. 10 The diagram of fast pyrolysis system

（图10 快速热解装置示意图）

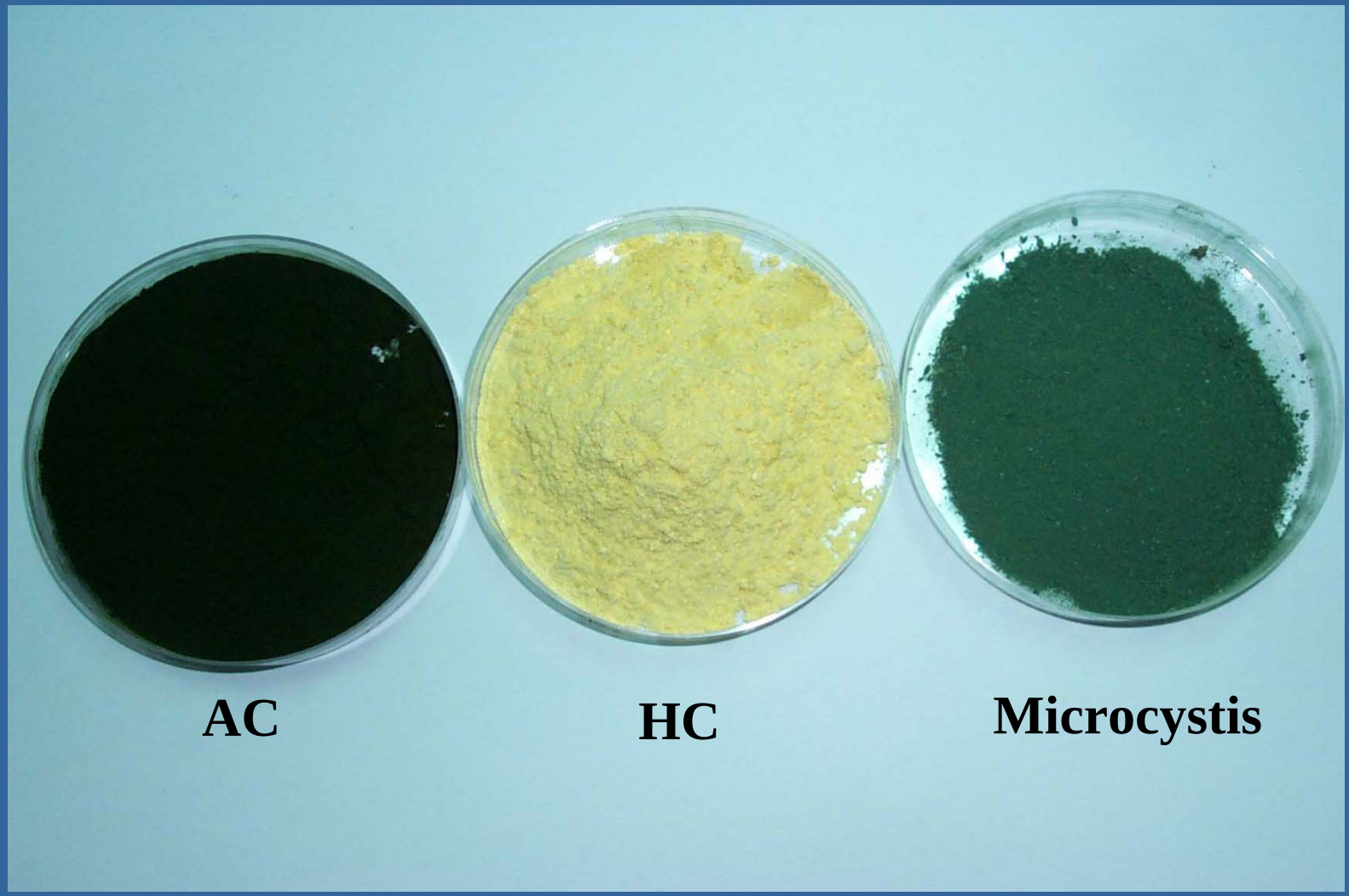


Fig. 11 Dry cells powder of AC, HC and *Microcystis* respectively.

（图11 自养（AC）、异养（HC）小球藻及微囊藻的干藻粉）

Table 2

Yields of fast pyrolysis at temperature of 500 ℃, heating rate of 600 ℃ /s and the sweeping gas flow rate of 0.4m^3/h.

（表2　微藻快速热解产率）

Strain	Gas (%)	Bio-Oil (%)	Char (%)
AC	29.6	16.6	53.8
HC	31.6	57.2	11.2
Microcystis	55.2	23.7	21.1

All the yields were expressed on the basis of the dry weight of samples.

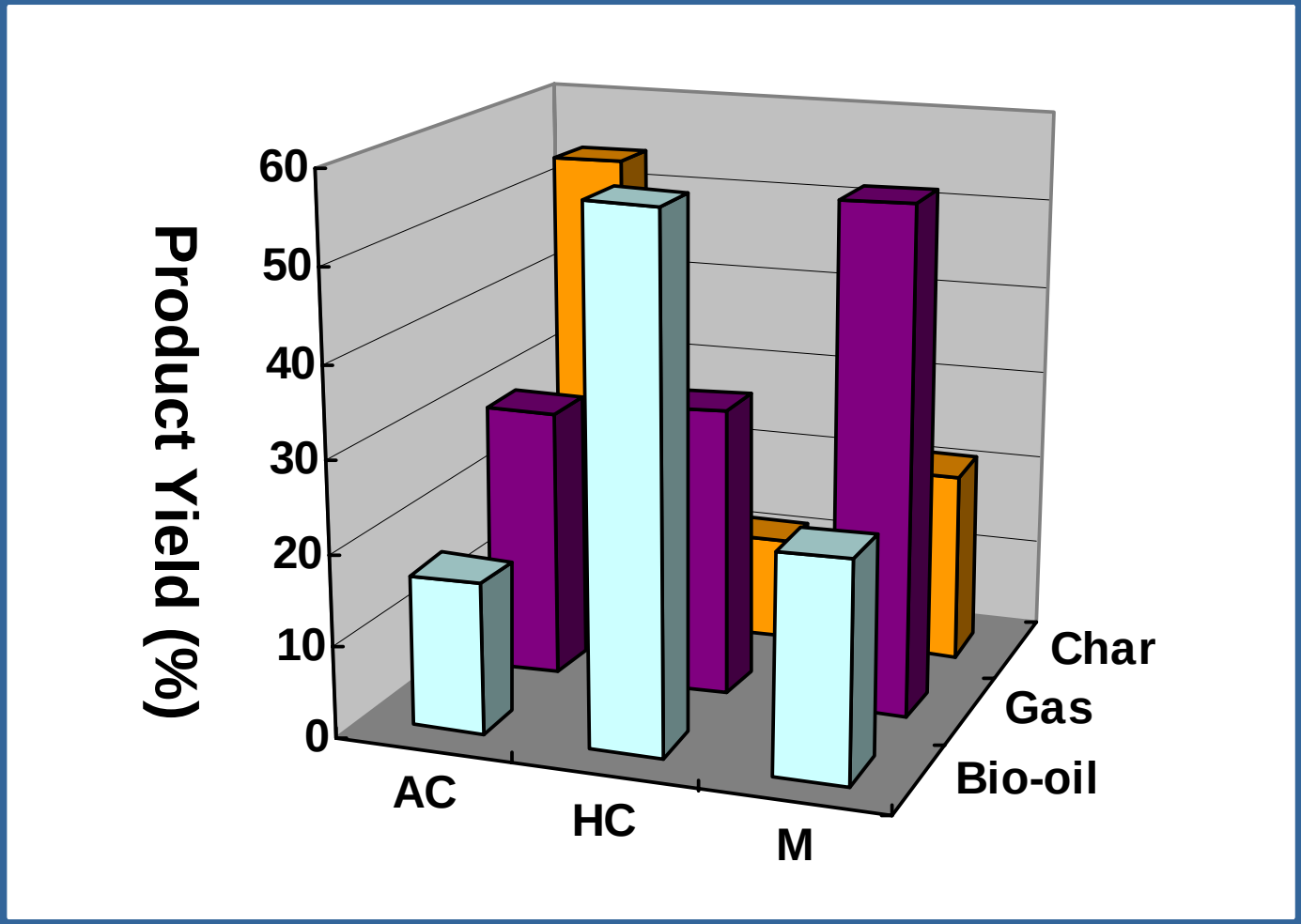


Fig. 12 Product yields of microalgae by fast pyrolysis at temperature of 500 ℃, heating rate of 600 ℃ /s and the sweeping gas flow rate of 0.4m^3/h.

(图12 微藻快速热解产物比率）

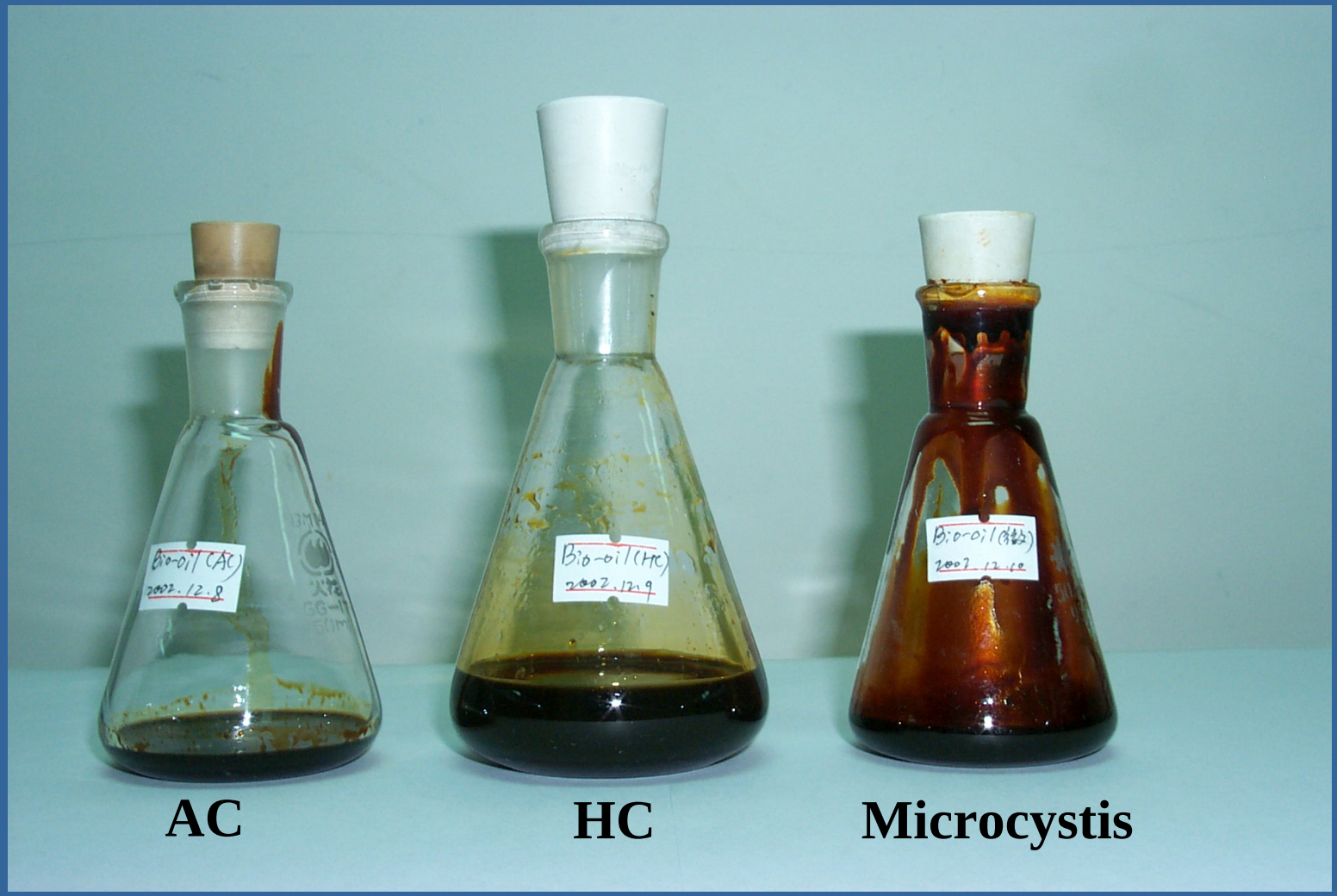


Fig. 13　Bio-Oil products of AC, HC and *Microcystis* by fast pyrolysis.

（图13　AC、HC 及微囊藻的快速热解油）

Table 3 Comparison of typical properties of fossil oil and fast pyrolysis oil of wood and HC.

Properties	Typical value			
	Bio-oils			Fossil oil
	Wood	AC	HC	
C	56.4%	62.07%	76.22%	83.0-87.0%
H	6.2%	8.76%	11.61%	10.0-14.0%
O	37.3%	19.43%	11.24%	0.05-1.5%
N	0.1%	9.74%	0.93%	0.01-0.7%
S	n.d.	n.d.	n.d.	0.05-5.0%
Density (kg l^{-1})	1.2	1.06	0.92	0.75-1.0
Viscosity (Pa s)	0.04-0.20 (at 40°C)	0.10 (at 40°C)	0.02 (at 40°C)	2-1000
Heating value (MJ kg^{-1})	21	30	41	42
Stability	Not as stable as fossil fuels	Not as stable as fossil fuels, but more stable than the bio-oil from wood		

Conclusions

Our research suggests that the new process, which combines bioengineering and fast pyrolysis, is a feasible and effective method for the production of high yield and high quality fuel oils from microalgae. The research could contribute to the creation of a system to produce energy from microalgae, and also could have great commercial potential for liquid fuel production.

[AC、HC 和 *Microcystis*三种藻的生化组成不同，性质不一样，热解特性也不同。所得的热解油产率差别较大，油的性质也有所不同。异养使HC细胞内脂肪含量提高375% (Table 1)，使其细胞的产烃能力增大，所得的油产率提高338% (是AC的3.4倍) (Table 2, Fig. 12)。通过热解条件的改进，有望进一步提高HC的产油率。]

Thank you !