US NSF – CHINA NSF WORKSHOP ON SUSTAINABLE MANUFACTURING

# Advances in 3E of Polymer Processing and Sustainable Manufacturing


**Beijing University of Chemical Technology**

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**Wuhan, China**
**March 13-15, 2014**

# Beijing University of Chemical Technology

On behalf of

## 高分子材料加工成形与先进制造创新团队

## Innovation Team of Polymer Processing Molding and Advanced Manufacturing

# Outline

1. **Challenges in Polymer Processing**
2. **Innovation on Sustainable Manufacturing**
3. **Conclusion and Future Work**

# 1. Challenges in Polymer Processing

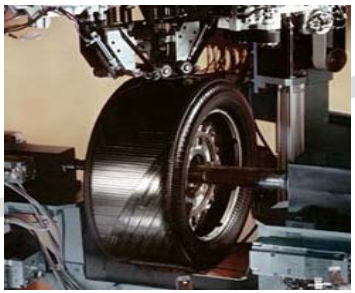
# 1. Challenges in Polymer Processing

## Manufacturing Sci. & Tech. has 4 research fields

**Inorganic no metal**
**Manufacturing**

**Organic Polymer**
**Manufacturing**

**Metal**
**Manufacturing**

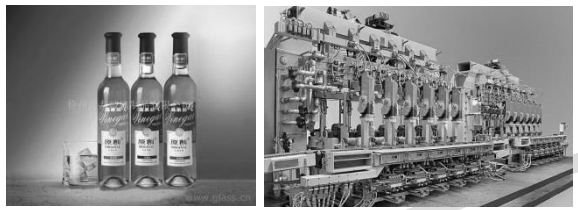


**Composites**
**Manufacturing**

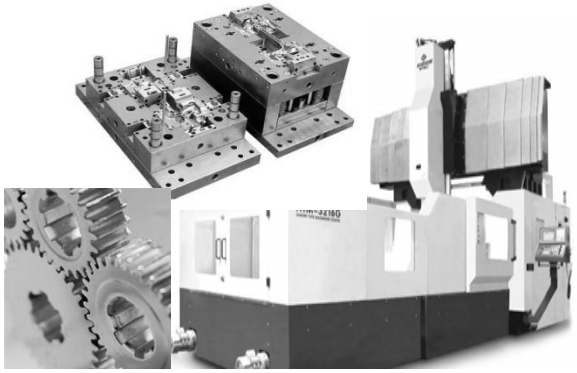
# 1. Challenges in Polymer Processing

My Research Team focus on

## Polymer Processing

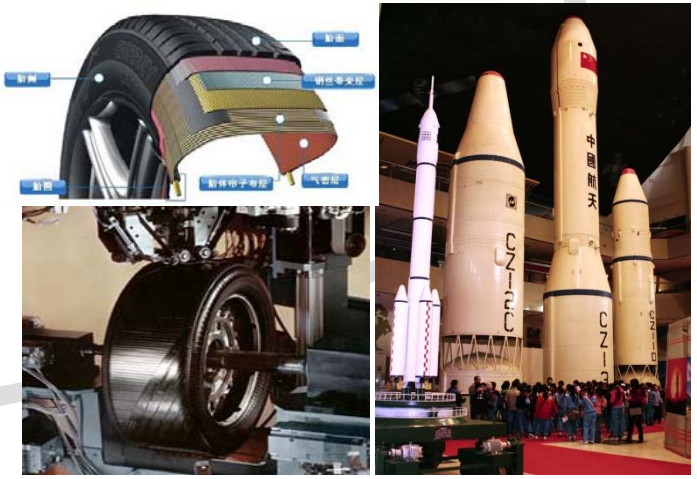


Inorganic no metal Manufacturing



Metal Manufacturing

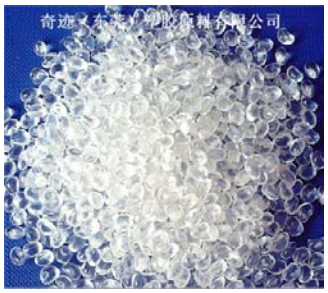
**Organic Polymer Manufacturing**



**Resin Matrix Composites Manufacturing**

# 1. Challenges in Polymer Processing

## Polymer Processing



Resin

**Pre-Processing**
Drying
Mixing
Blending
……

**Molding**
Extrusion
Injection
Rotational
……
Composite

**Post-Processing**
Vulcanization
Cross-linking
Joining
……

Products

# 2. Innovation on Sustainable Manufacturing

**3E: Efficiency, Energy-saving, Environment- friendly**

# 2. Innovation on Sustainable Manufacturing

**3E: Efficiency, Energy-saving, Environment- friendly**

# 2. Innovation on Sustainable Manufacturing

**3E: Efficiency, Energy-saving, Environment- friendly**

## Near net shape forming technology is in dominant position of polymer processing

**Injection Molding** is a good example


**近净成形在聚合物加工中占主导地位**



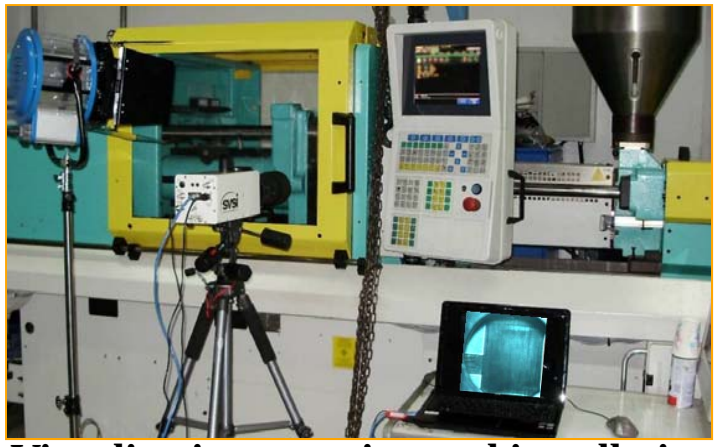
# 2. Innovation on Sustainable Manufacturing

**3E: Efficiency, Energy-saving, Environment- friendly**

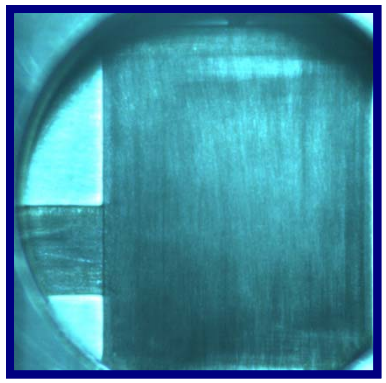
## Problems

## Injection Molding

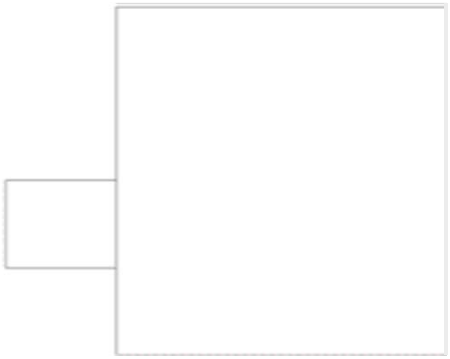
What's the filling behavior and Why in the "black box" mold
How to discover it so as to make nice products



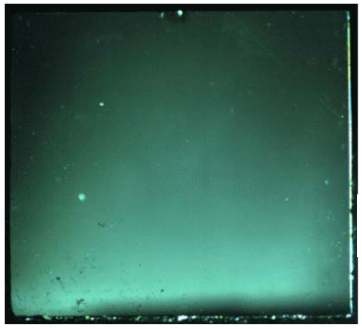
Visualization experimental installation



1) Filling Process



Simulation

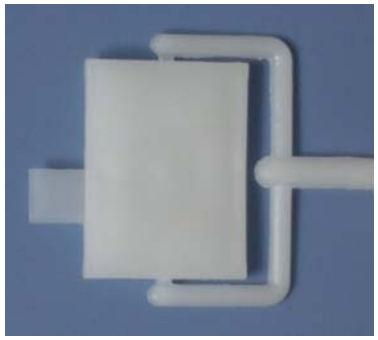


2) Internal Stresses

**How**

**Performance & Shape**

**成性 + 成形**



Test Sample

# 2. Innovation on Sustainable Manufacturing

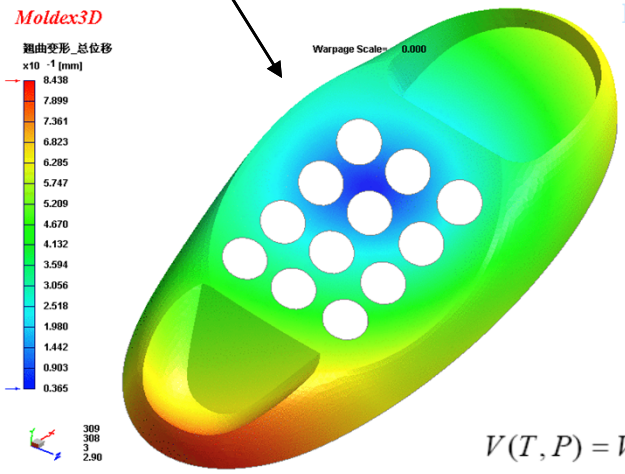
**3E: Efficiency, Energy-saving, Environment- friendly**

## Problems

**Shrinking and Warping**

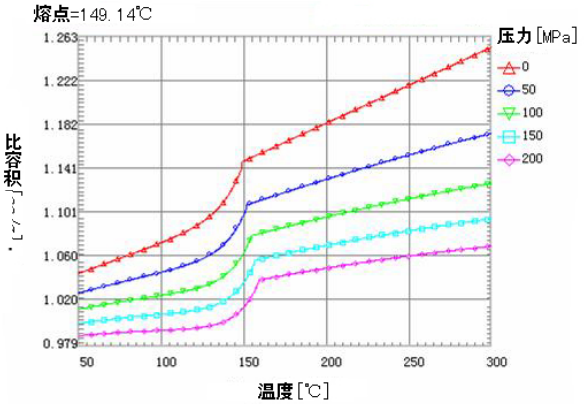
## Injection Molding

Discover the Deformation laws of polymer molding is important & difficult




**P ➡ V ⬅ T**

$$V(T,P) = V_0(T)\left\{1 - C\ln\left[1 + \frac{P}{B(T)}\right]\right\} + V_1(T,P)$$




**Nonlinear PVT properties**

**3) Deformation Laws**

**P** Pressure
**V** Volume
**T** Temperature

**How**

**Precision Control**

# 2. Innovation on Sustainable Manufacturing

**3E: Efficiency, Energy-saving, Environment- friendly**

## Key Problem

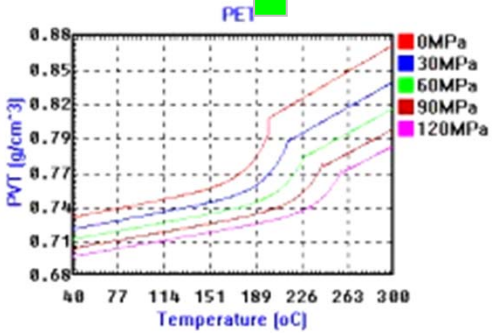

**Beam Caliper**

**How to control the molding precision ?**

**如何控制精度？**

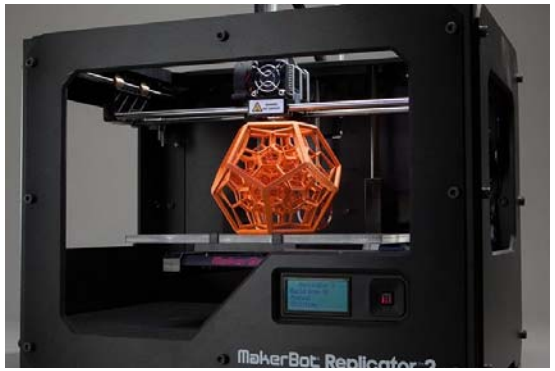
The only answer is,
By PVT Properties
But not by calipers

**PVT**




**Metal Cutting**

**Polymer Molding**
**（3D copying）**




**Polymer Rapid Prototype**
**（3D printing）**

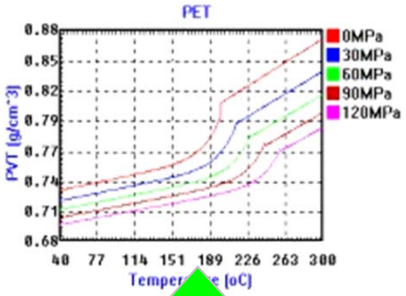
# 2. Innovation on Sustainable Manufacturing

**3E: Efficiency, Energy-saving, Environment- friendly**

**Key Problem** **How can we get PVT property ?**

$$V(T,P) = V_0(T)\left\{1 - C\ln\left[1 + \frac{P}{B(T)}\right]\right\} + V_1(T,P)\ .$$

**USA Gnomix**




**Japan Toyo Seikei**

**Germany SWO**

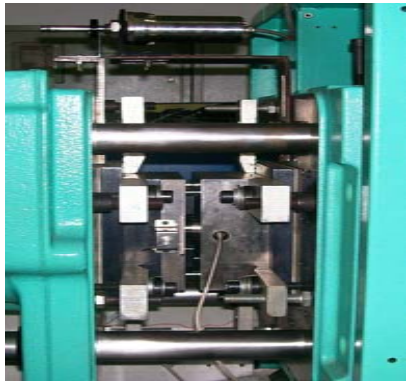
# 2. Innovation on Sustainable Manufacturing

**3E: Efficiency, Energy-saving, Environment- friendly**

## Research

## We invented a PVT tester

**Patent: ZL200710063461.3**

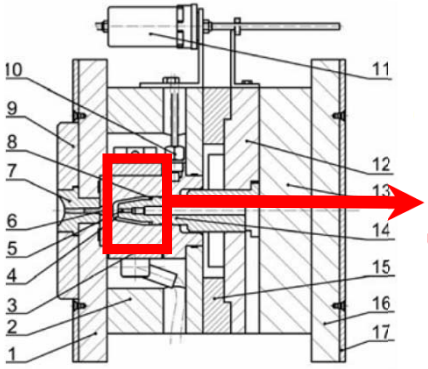


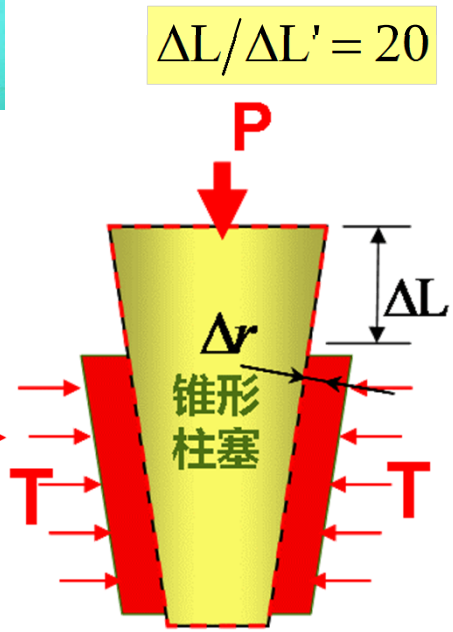
**Amplified factor=20**

**Amplified factor= 0**

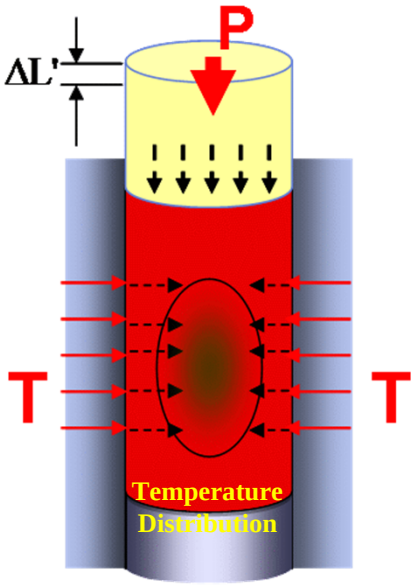
Please pay attention to the difference of the

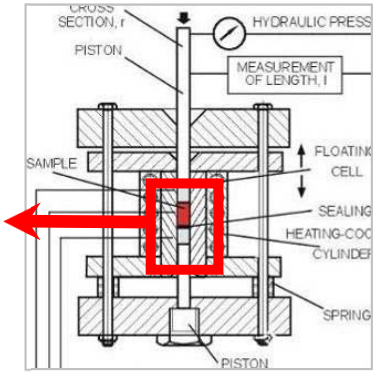
## PVT Test Mechanism






**China BUCT**




**USA , Germany, Japan**

# 2. Innovation on Sustainable Manufacturing

**3E: Efficiency, Energy-saving, Environment- friendly**

## Result and Application

**It was applied in China Haitian's IMM, and result in high precision level.**

**Injection Molding Machine**
**Precision Level 0.037%**


**Haitian Group Ltd.**

国家塑料机械产品质量监督检
National Quality Supervision and Inspection Center
检 验 结 果
TEST RESULTS

No: SJW20090256 第 6

| 序号 Series Number | 检验项目 Test Items | 标准（技术）要求 Requirement | | 型号规格 Model | 样品编号 Sample No. | | |
|---|---|---|---|---|---|---|---|
| 17 | 总装质量 | 移动模板与固定模板的模具安装面间的平行度 | 合模力为零时：≤0.50mm | MA4700/2950 | SJW20090256-1 | | |
| | | | 合模力最大时：≤0.25mm | MA4700/2950 | SJW20090256-1 | | |
| 18 | 液压系统工作油温 | ≤60℃ | | MA4700/2950 | SJW20090256-1 | 48℃ | 合格 |
| 19 | 液压系统密封性 | 在额定工作压力下，允许渗油处数：≤3处 | | MA4700/2950 | SJW20090256-1 | 未见渗漏 | 合格 |
| 20 | 整机噪声 | ≤83dB(A)（声压级） | | MA4700/2950 | SJW20090256-1 | 74dB(A) | 合格 |
| 21 | 整机外观要求 | 整机外观应整洁美观、颜色和谐。 | | MA4700/2950 | SJW20090256-1 | 符合 | 合格 |
| | | 涂漆表面应符合HG/T 3228-2001中的3.4.5的规定。 | | MA4700/2950 | SJW20090256-1 | 符合 | |
| 22* | 制品质量重复精度 | 实测 | | MA4700/2950 | SJW20090256-1 | 0.37‰ | 仅提供实测值 |
| | | | | SA4700/2950 | SJW20090256-2 | 0.92‰ | |
| | | | | SA4700/2950v | SJW20090256-3 | 1.11‰ | |
| 23* | 能耗 | 实测 | | MA4700/2950 | SJW20090256-1 | 0.40kWh/kg | 仅提供实测值 |
| | | | | SA4700/2950 | SJW20090256-2 | 0.60kWh/kg | |
| | | | | SA4700/2950v | SJW20090256-3 | 0.50kWh/kg | |

# 2. Innovation on Sustainable Manufacturing

**3E: Efficiency, Energy-saving, Environment- friendly**

## Result and Application

USA PLASTICS NEWS said:
Haitian overtakes global giants

PLASTICSNEWS.com

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### Haitian overtakes global giants

By Steve Toloken | PLASTICS NEWS STAFF
Posted October 1, 2010


Here's a reality check on how business is realigning globally: The largest injection press maker in the world may no longer be European or Japanese or North American, but Chinese.

Haitian International Holdings Ltd. probably has the largest world revenues making injection molding machines.

The Ningbo-based company was No. 5 in global sales in 2005, but growth in China and other emerging markets, coupled with the crisis in developed economies, has likely pushed it to the top.

Contents lists available at ScienceDirect

Polymer Testing

journal homepage: www.elsevier.com/locate/polytest

Test Equipment

### On-line testing equipment of P–V–T properties of polymers based on an injection molding machine

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ARTICLE INFO

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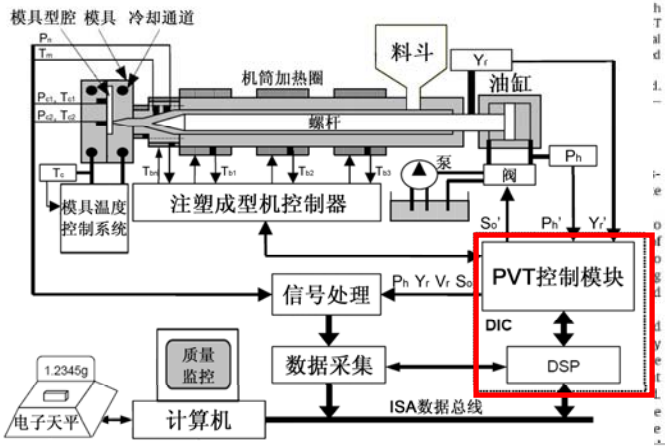
P–V–T relationships
On-line testing
Testing mold

ABSTRACT

In order to obtain more accurate prediction of the service performance and service life of polymers and the optimization of processing parameters, this paper presents a novel, on-line testing equipment for measuring P–V–T (Pressure–Volume–Temperature) relationships of polymers under processing conditions. This equipment is based on an injection molding machine (IMM), and it can be used to get P–V–T data of polymers directly with a special testing mold under normal processing conditions. P–V–T properties of five polymers (ABS, PS, LDPE, PA 6 and PP) were measured. The experimental results under industrial processing conditions were presented. The results were compared with those



# 2. Innovation on Sustainable Manufacturing

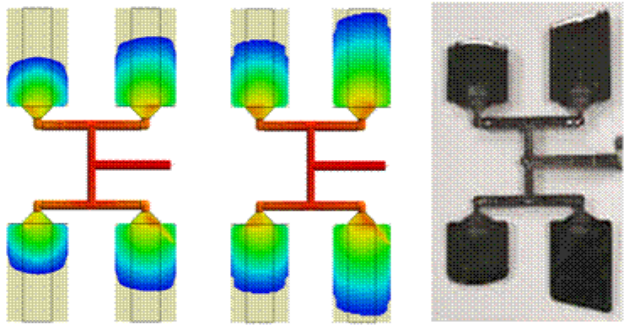
**3E: Efficiency, Energy-saving, Environment- friendly**

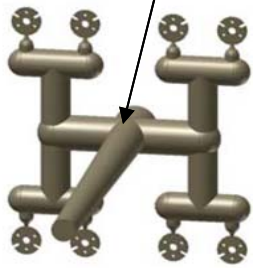
# 2. Innovation on Sustainable Manufacturing

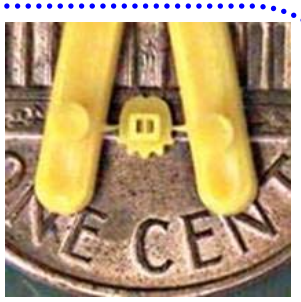
**3E: Efficiency, Energy-saving, Environment- friendly**

**Problems** **There exists Material and Energy Waste**

**In molding micro parts for 3C products, more than 90% materials will be recycled for many times, or molding it by many micro Injection Molding Machines**







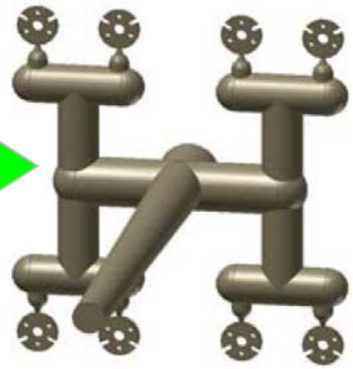
# 2. Innovation on Sustainable Manufacturing

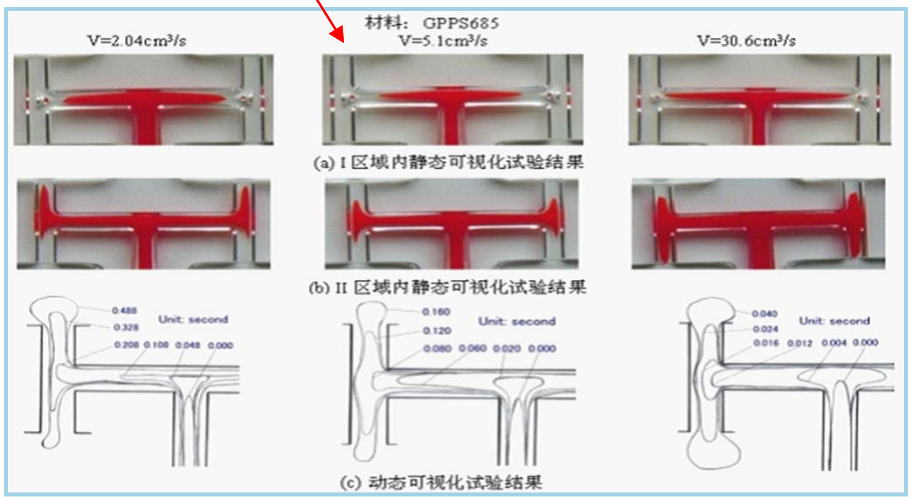
**3E: Efficiency, Energy-saving, Environment- friendly**

## Research

**We studied the imbalance flow behavior, and understand that it's due to the asymmetric shearing heat distribution.**

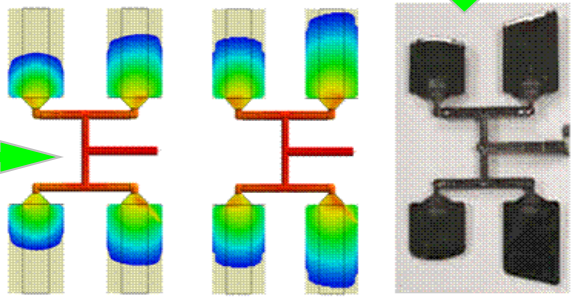
**Big**

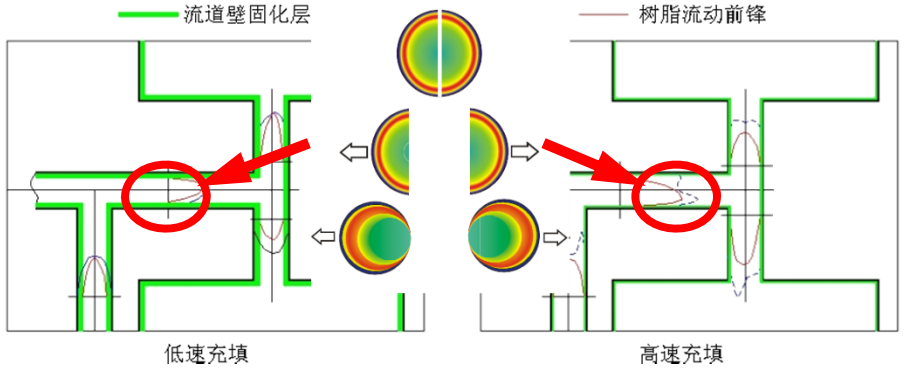





**Imbalance flow in molding** ← **Unsymmetrical Shearing heat distribution**

**small**





# 2. Innovation on Sustainable Manufacturing

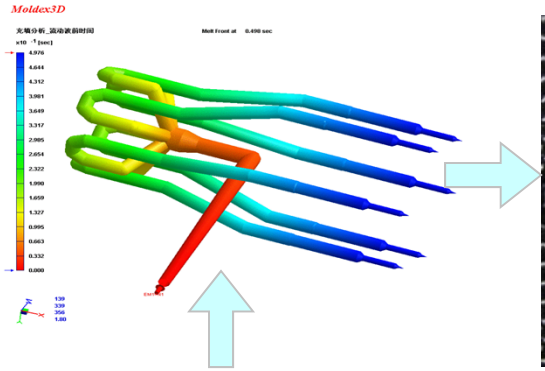
**3E: Efficiency, Energy-saving, Environment- friendly**

## Result and Application

**We proposed a New Concept : Melt Differential Theory for polymer processing**

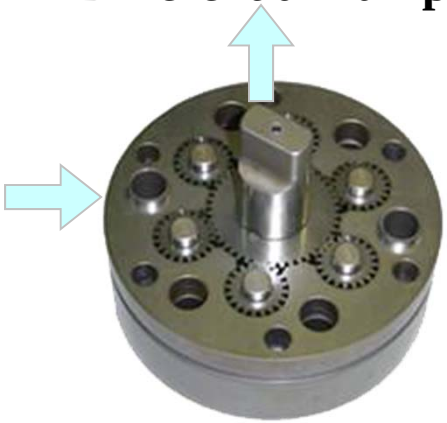
**And then invented Differential Injection Molding**

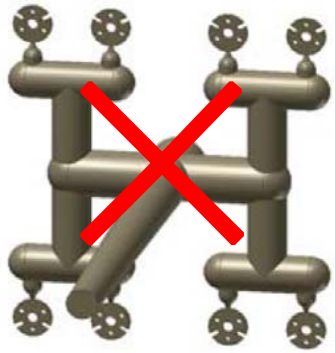
Patent: **ZL200810227241.4**




**Hot Runner of Differential Pump**

**Energy & Mater. Waste = 0**



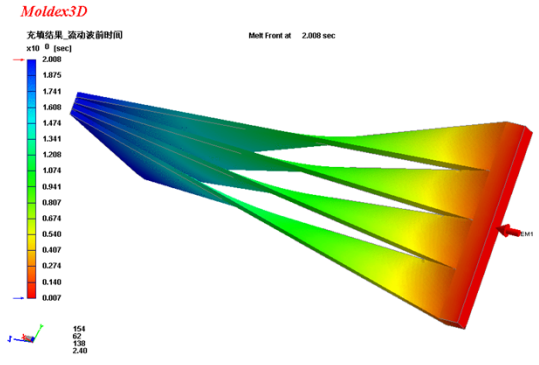


# 2. Innovation on Sustainable Manufacturing

**3E: Efficiency, Energy-saving, Environment- friendly**

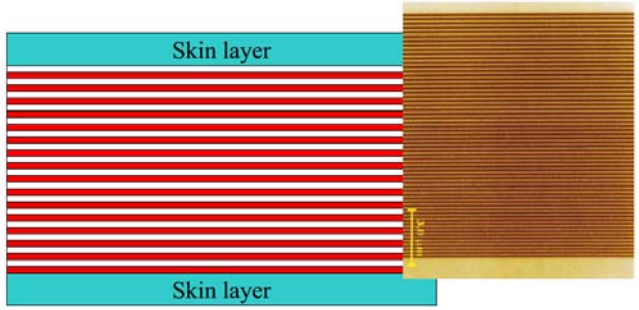
## Result and Application

**We also invented Melt Differential Extrusion Molding Method**




China Patent： ZL200910237622.5

USA Patent： 3557265

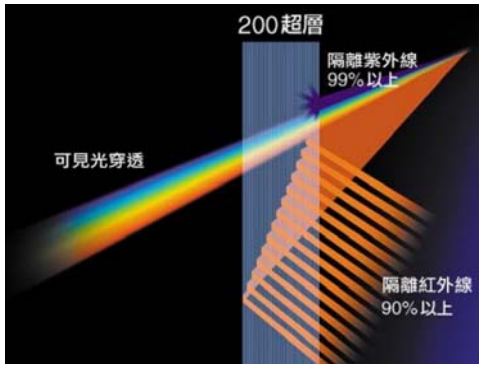



100-1000 layer, Nano-structure

**Meta**

**Materials**

**超材料**

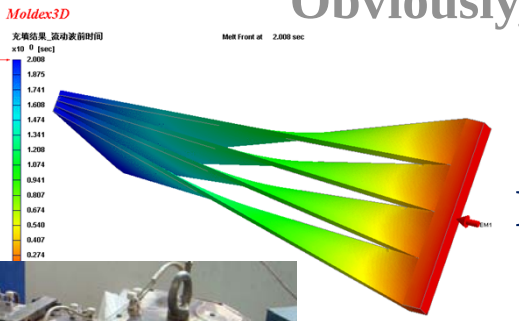


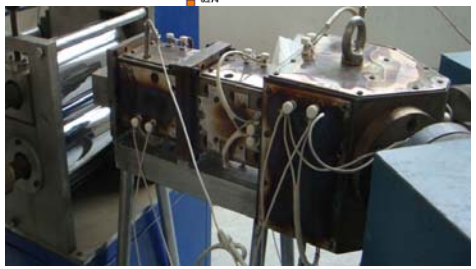
# 2. Innovation on Sustainable Manufacturing

**3E: Efficiency, Energy-saving, Environment- friendly**

## Result and Application

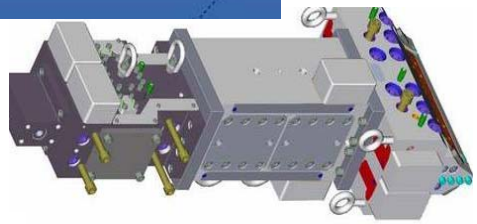
**Obviously, flow easily result in Energy-saving**



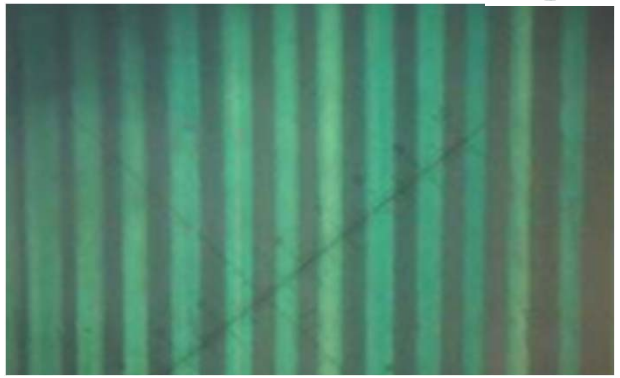
**China BUCT**

**Mechanism**

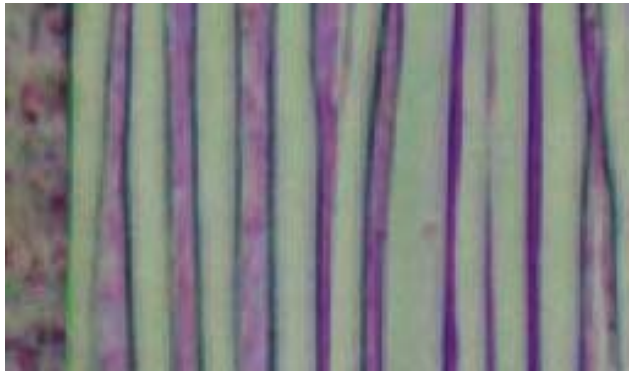


**Different**

**USA**



**Result**



**Micro layer Structure**

# 2. Innovation on Sustainable Manufacturing

**3E: Efficiency, Energy-saving, Environment- friendly**

**Problems** **Energy Waste Rubber Industry**

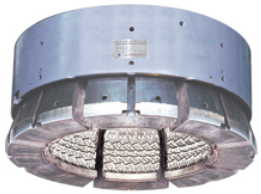
Tire vulcanization heating by water vapor.

The inside rubber mold is badly poor in heat transfer.

**Tire vulcanization machines**

## Tire mold

**Outside (steel)**



**Inside (rubber)**

# 2. Innovation on Sustainable Manufacturing

**3E: Efficiency, Energy-saving, Environment- friendly**

## Problems Energy Waste Rubber Industry

**Huge tire vulcanization heating time is long to 10 hours.**
**Energy-saving method is very important.**


**Inside mold (rubber)** **Outside mold (steel)**

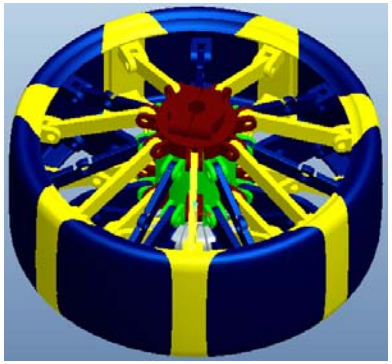


# 2. Innovation on Sustainable Manufacturing

**3E: Efficiency, Energy-saving, Environment- friendly**

**Research** **We developed efficient heat transfer method, and invented a new vulcanization equipment.**

**Rubber mold**

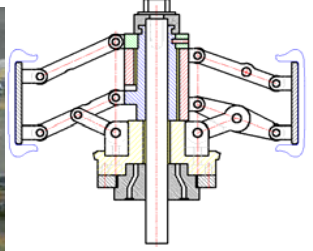


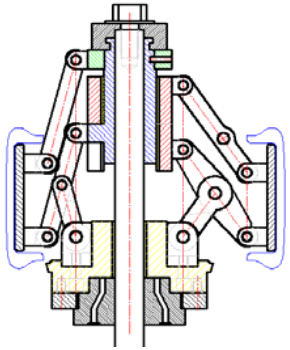
**Steel mold**

**water vapor**

**Electromagnetic**

**Patent: 201210157510.0**





# 2. Innovation on Sustainable Manufacturing

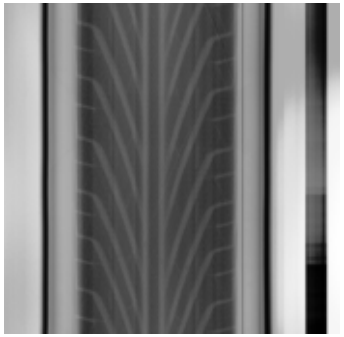
**3E: Efficiency, Energy-saving, Environment- friendly**

## Result and Application

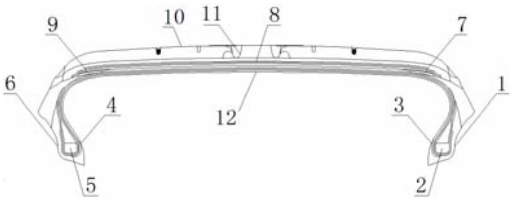
**Performance increased & Energy saving 8~10% !**

**Outside surface**

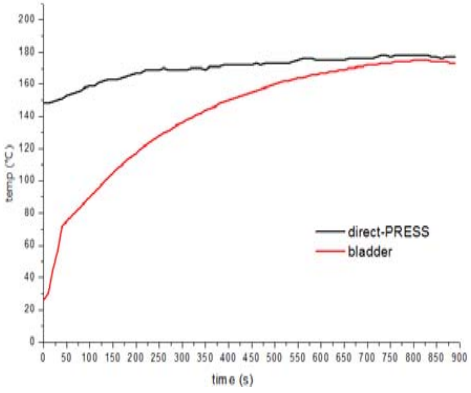
**Inside surface**



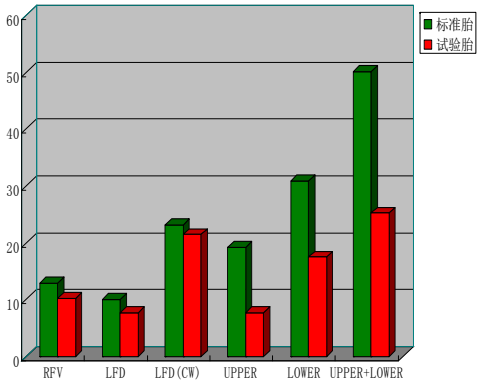
**X-ray Test result**




**Temperature test points**




**Temperature curve**




**Molding precision (Tolerance)**

**High speed test**

**Durability test**

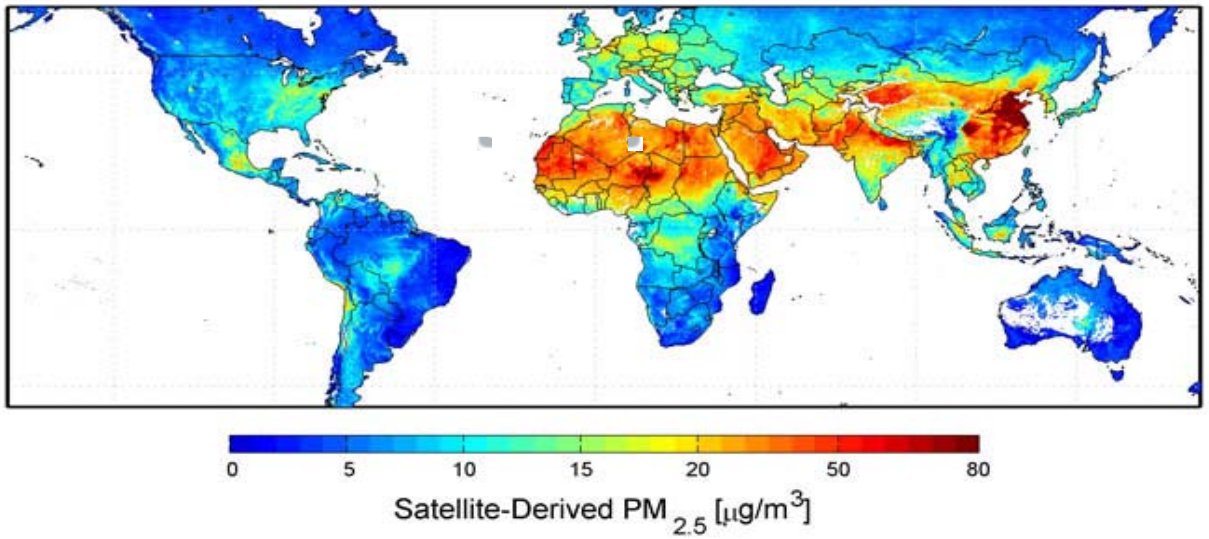
# 2. Innovation on Sustainable Manufacturing

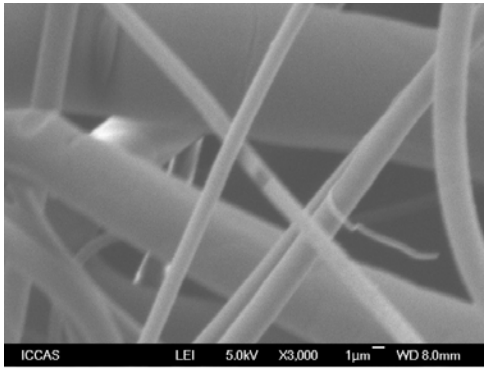
**3E: Efficiency, Energy-saving, Environment- friendly**

# 2. Innovation on Sustainable Manufacturing

**3E:** Efficiency, Energy-saving, **Environment- friendly**

**Problems** **PM2.5 Pollution** **need Micro and nano-fiber**

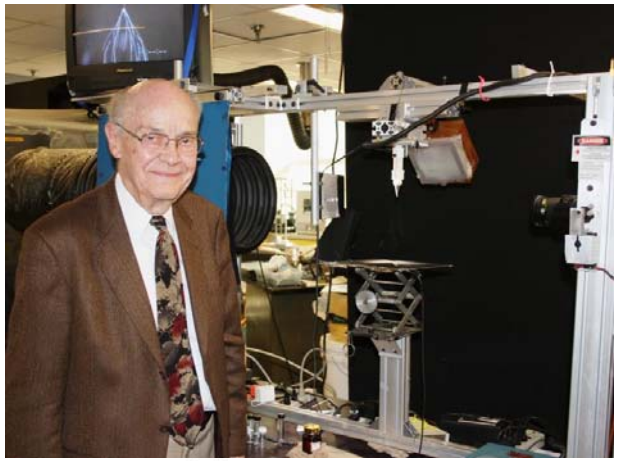


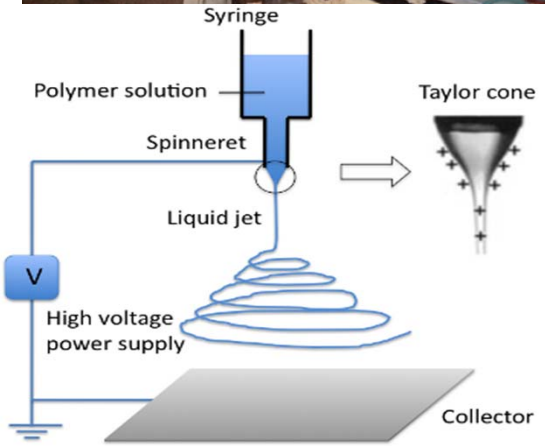

# 2. Innovation on Sustainable Manufacturing

**3E: Efficiency, Energy-saving, Environment- friendly**

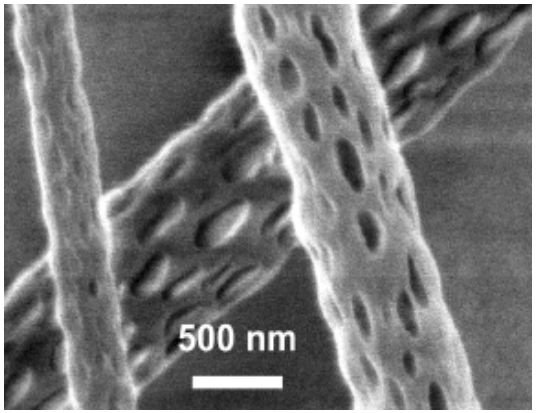
**Problems** **The best way to make nano-fiber is Electro-spinning**



**Prof. Reneker in USA , has greatly promoted Polymer solution electro-spinning technology**




**Polymer Solution Electro-spinning**



# 2. Innovation on Sustainable Manufacturing

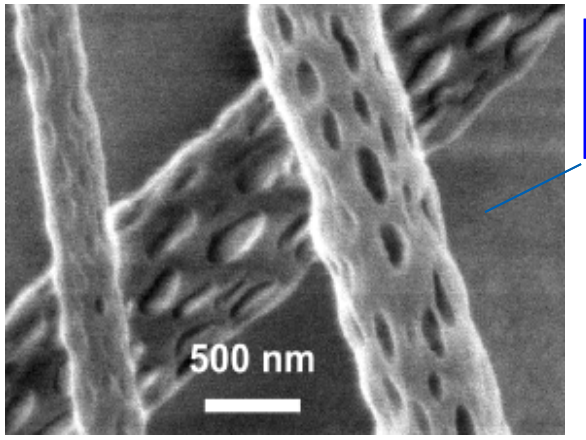
**3E: Efficiency, Energy-saving, Environment- friendly**

## Problems

**In 2010 Shanghai World Expo** Czech put forward **nano spider**

Czech






**Polymer solution electro-spinning**

**3 Shortages:**

**Low strength of fiber.** Defects caused by solvent evaporation

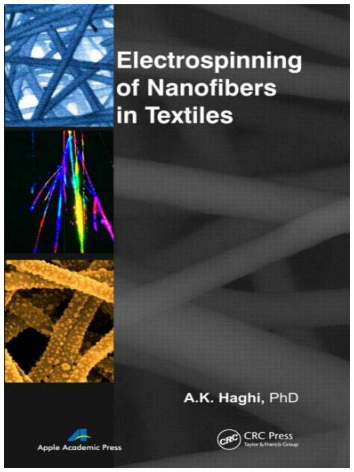
**Low productivity.** < 5% of the solution become fibers

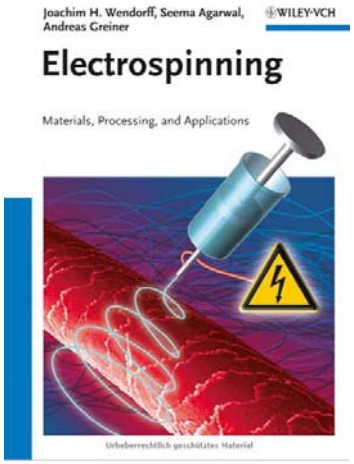
**Solvent pollution.** & PP, PE can not find solvent

# 2. Innovation on Sustainable Manufacturing

**3E: Efficiency, Energy-saving, Environment- friendly**

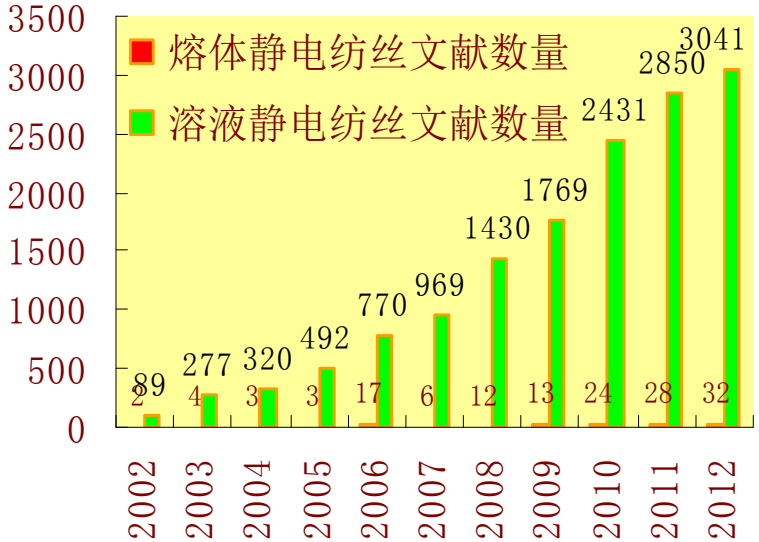
## Research Progress in Melt Electro-spinning






**Books & papers published during the past 10 years:**




**Only 1% of the published papers is about Melt-Electro-Spinning**

**We started this research from 2005, and find it was limited by method and equipments.**

# 2. Innovation on Sustainable Manufacturing

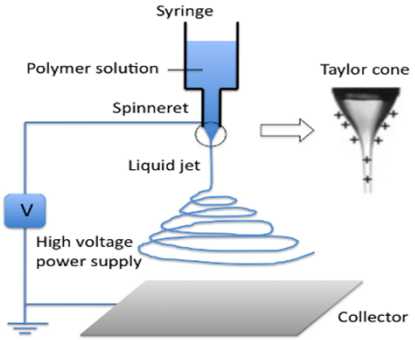
**3E: Efficiency, Energy-saving, Environment- friendly**

## Research

**Then we invented Melt Differential Electro-spinning Method**

As you know, Capillary electro-spinning is like a water tap:

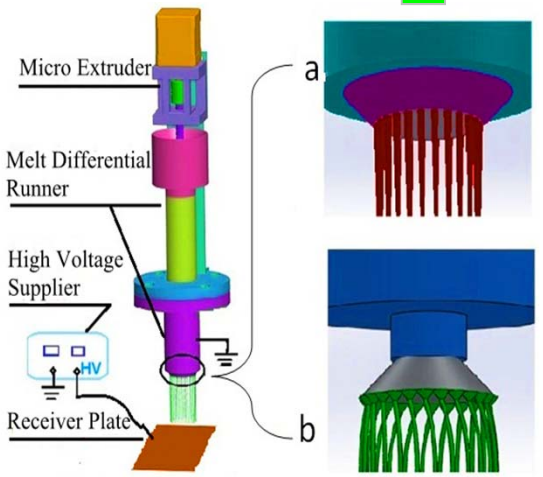
**Polymer Solution Electro-spinning**




**No Solvent pollution**
**Energy saving**
**High efficiency**


**Inspiration from nature waterfall**

**Melt Differential Electro-spinning**

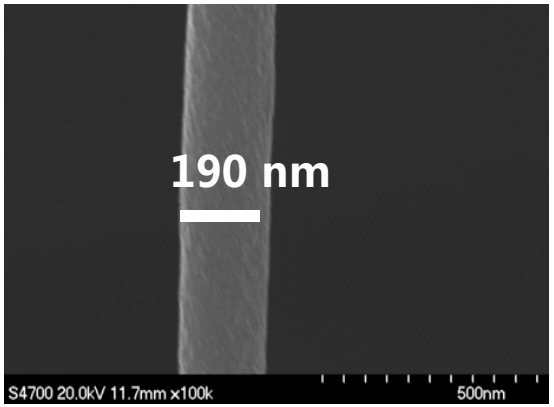


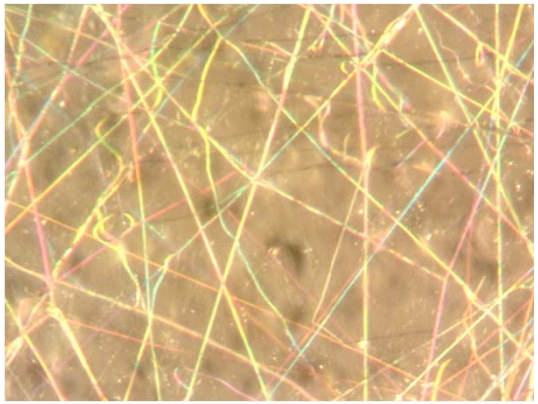
# 2. Innovation on Sustainable Manufacturing

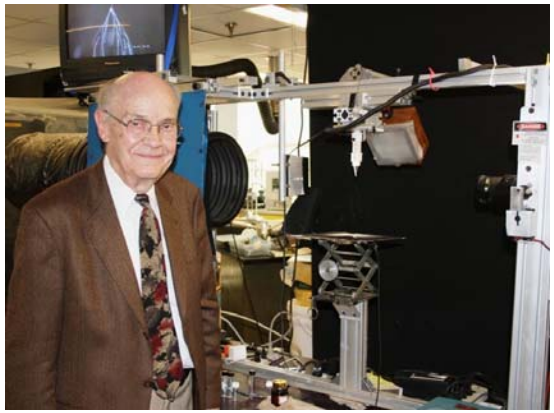
**3E: Efficiency, Energy-saving, Environment- friendly**

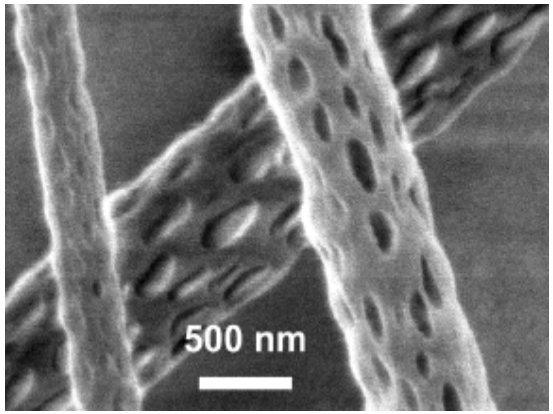
## Result and Application

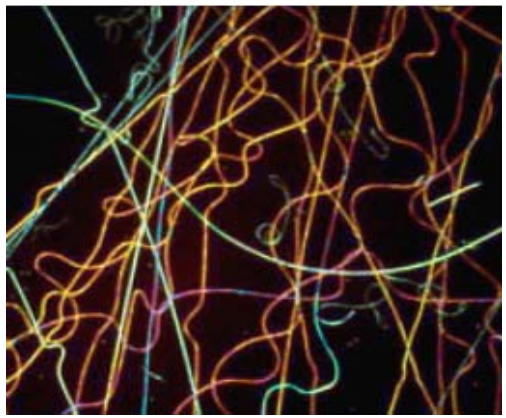
**We are doing very interesting work ,and got lot of superfine fibers shown as the upside pictures, it is colorful because the diameter is as small as light wavelength**







# 2. Innovation on Sustainable Manufacturing

**3E: Efficiency, Energy-saving, Environment- friendly**

## Result and Application

**Up to now, we hold 14 Patents published 23 papers.**

**Our new theory explaining the mechanism of Melt electro-spinning:**

**Melt Differential Tug of war effect**


Journal of Non-Newtonian Fluid Mechanics 202 (2013) 131–136

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journal homepage: http://www.elsevier.com/locate/jnnfm

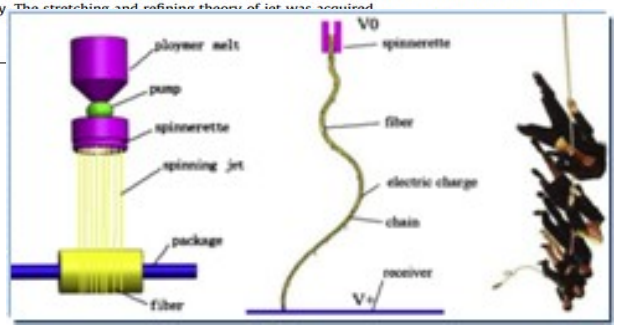
Tug of war effect in melt electrospinning

Zhaoxiang Liu, Yong Liu, Yumei Ding, Haoyi Li, Hongbo Chen, Weimin Yang*

College of Mechanical and Electrical Engineering, Beijing University of Chemical Technology, Beijing 100029, China

ABSTRACT

Solution electrospinning (ESP) has been deeply investigated currently. However, the research of melt ESP remains silent except a few progresses in device improvements and process investigation. In order to get a deeper understanding of fiber characteristics in the melt ESP process, microscopic simulation method of dissipative particle dynamics (DPD) was used here to create ESP simulation system. Fiber dropping process and the effect of spring coefficient on Tug of war effect were successfully simulated. In addition, the theory of Tug of war effect and the effect of factors on it were simulated and studied systematically. Results showed that distance between two particles and end-to-end distance of chains had the same variation tendency.




**New technology: Production Line**

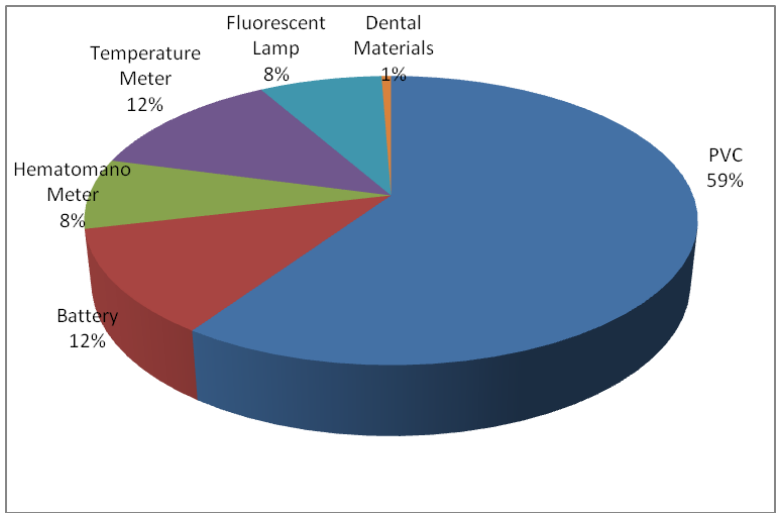
# 2. Innovation on Sustainable Manufacturing

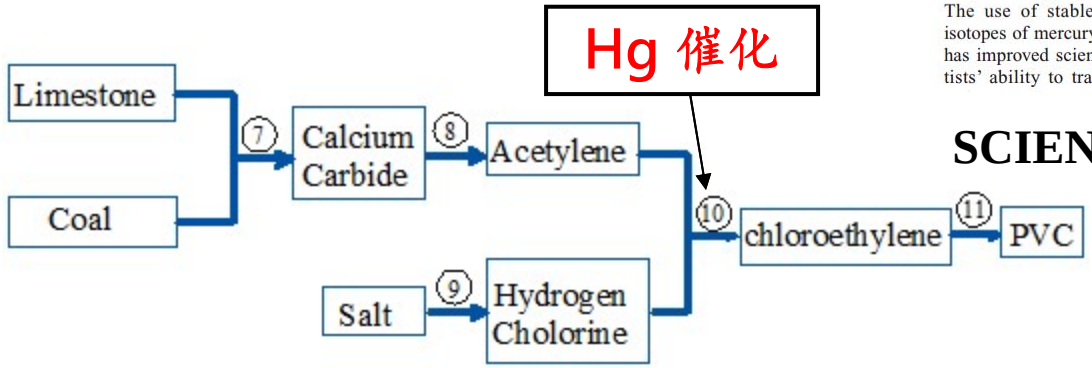
**3E: Efficiency, Energy-saving, Environment- friendly**

## Big Problem

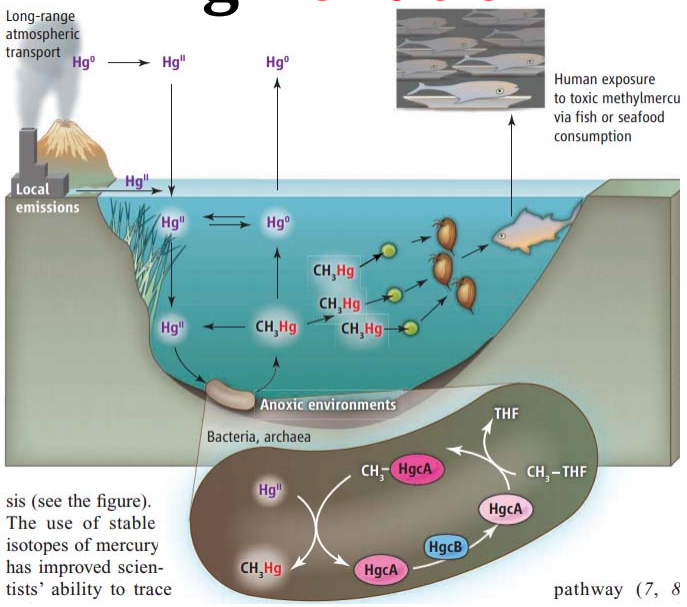
**Finally, I have to remind a very serious problem in polymer industry—Mercury Pollution**
**China is the largest country in mercury consumption, 59% used in PVC producing.**

**China Mercury Consumption Map**




## Hg Pollution




sis (see the figure). The use of stable isotopes of mercury has improved scientists' ability to trace pathway (*7*, *8*

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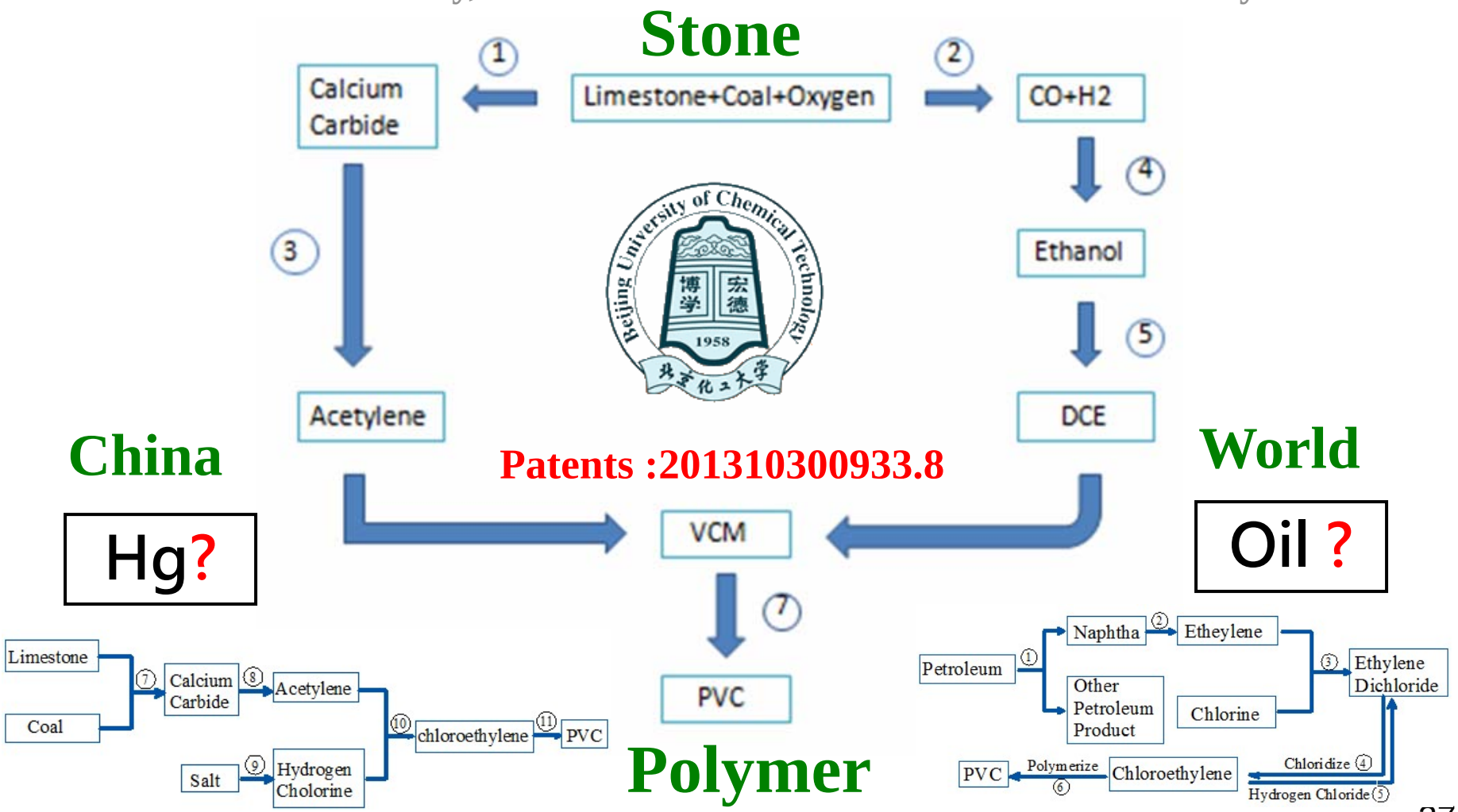
# 2. Innovation on Sustainable Manufacturing

**3E: Efficiency, Energy-saving, Environment- friendly**

**In order to solve the Oil dependence and mercury pollution in Polymer Chemical industry, We invented an Eco-method from Stone to Polymer**



# 3. Conclusion and future work

# 3. Conclusion

## Advances in Sustainable Manufacturing of Polymer Processing

**1. Developed: Scientific instruments and equipments**

- Visualization equipment of polymer injection molding
- PVT test equipment of polymer processing
- Polymer Melt Electro-spinning equipment

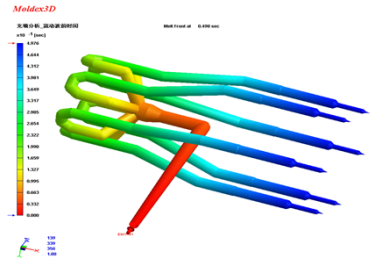
**Important discovery and know how to do better**

- Filling balance related with Shearing heat distribution
- PVT properties depend on Shearing rate/ T & P gradient
- Polymer Melt Differential Law and Tug of War in ES

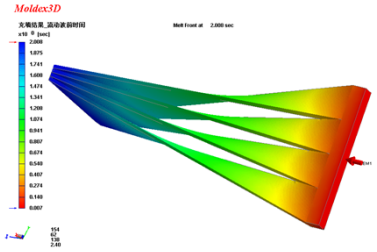
# 3. Conclusion

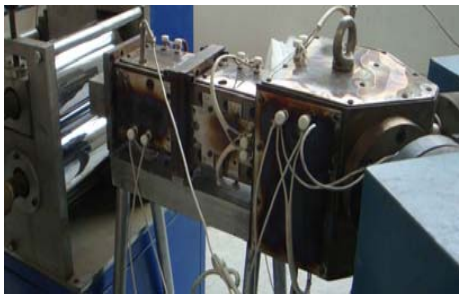
## 2. Invented and developed some 3E method and machines

**Efficient micro injection molding**

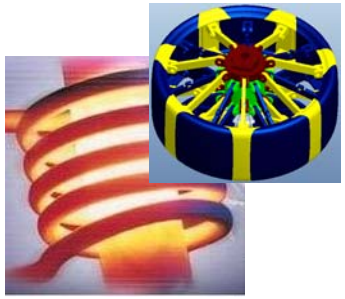



**Energy saving Extrusion molding**

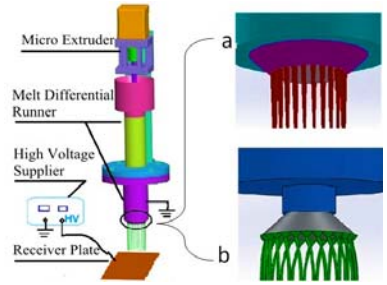


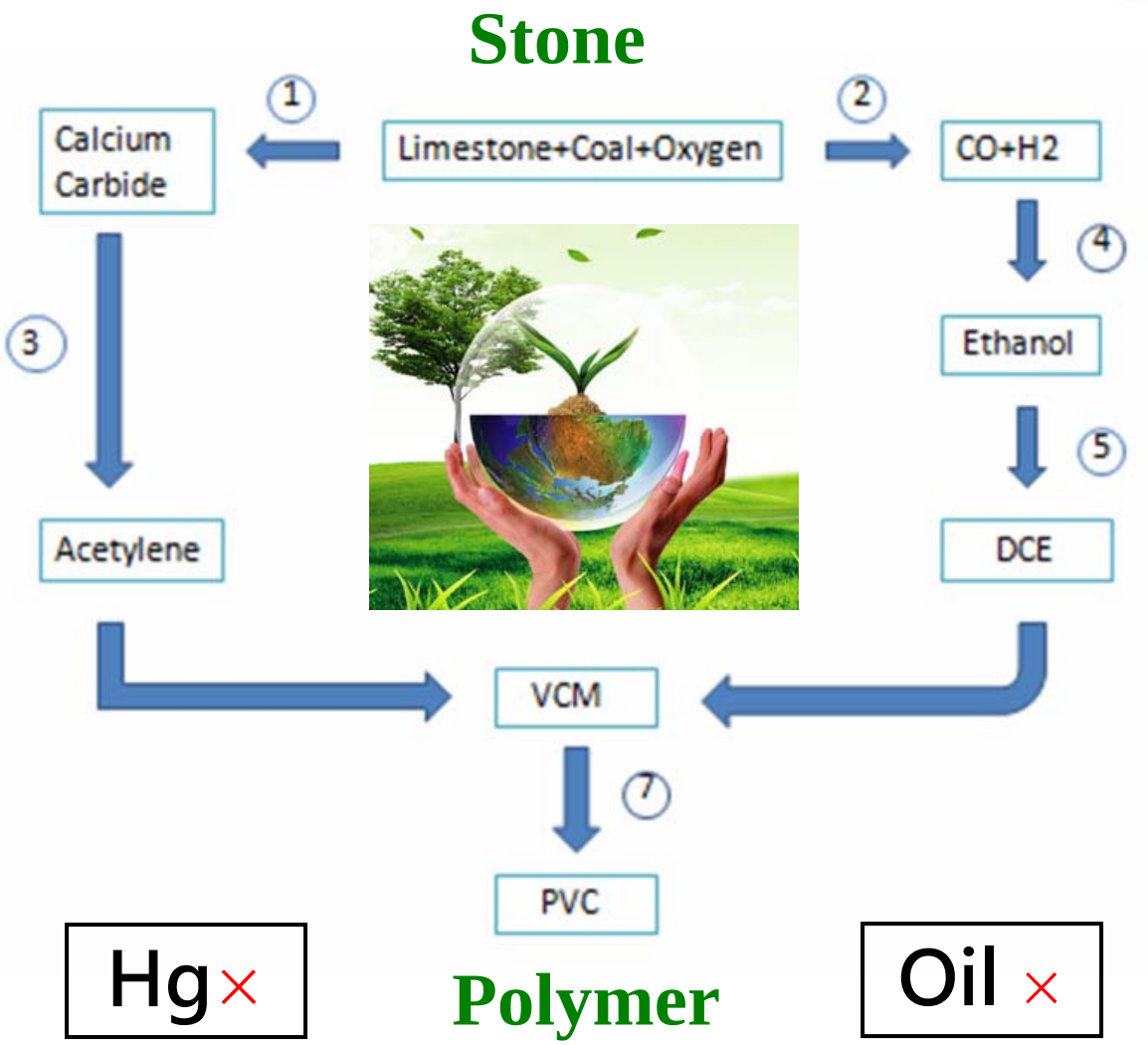
**Energy saving radial tire manufacturing**



**Environmental friendly Melt ES**



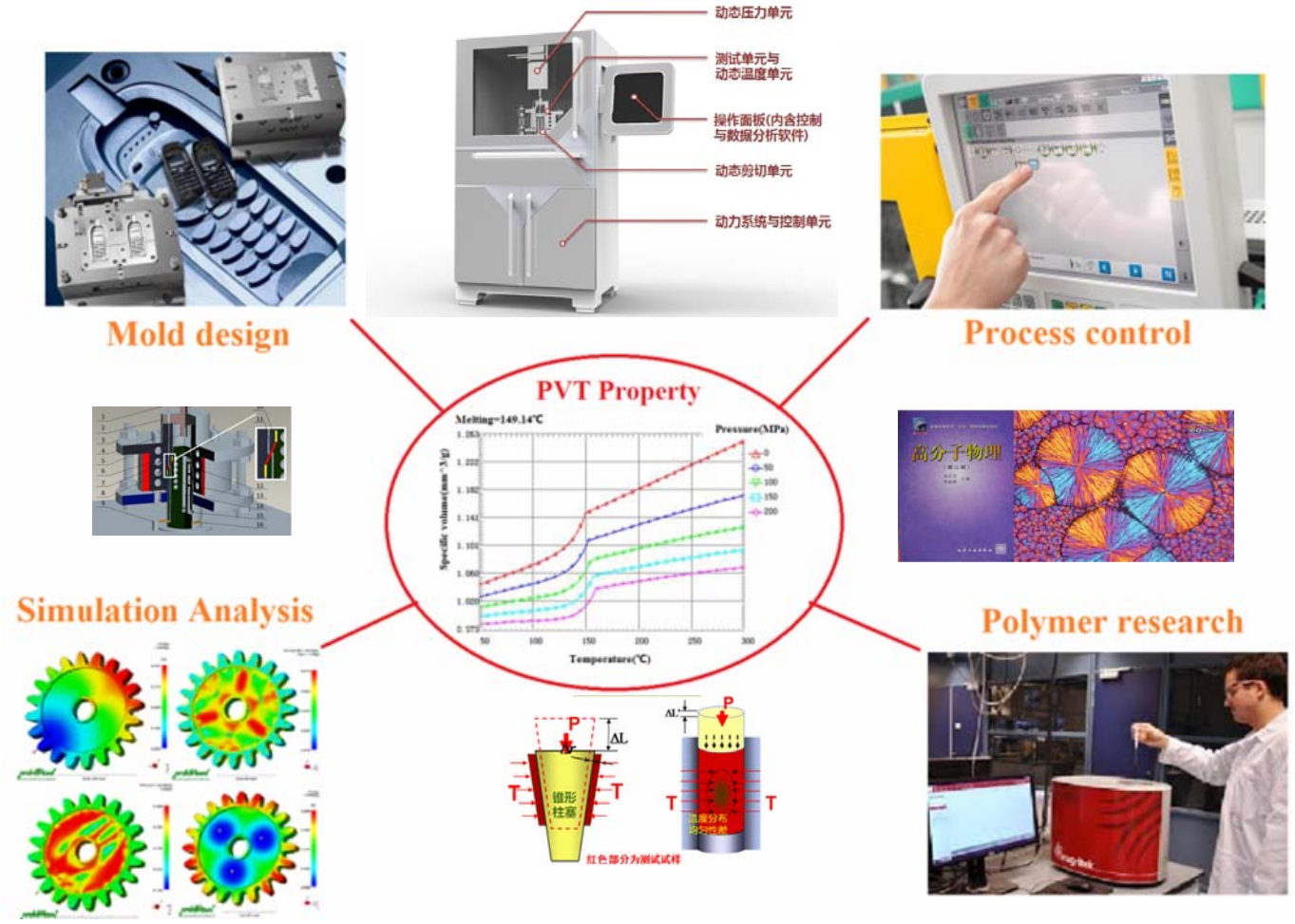

# 3. Future work




Mechanical + Chemical =Environmental friendly organic materials

# 3. Future work

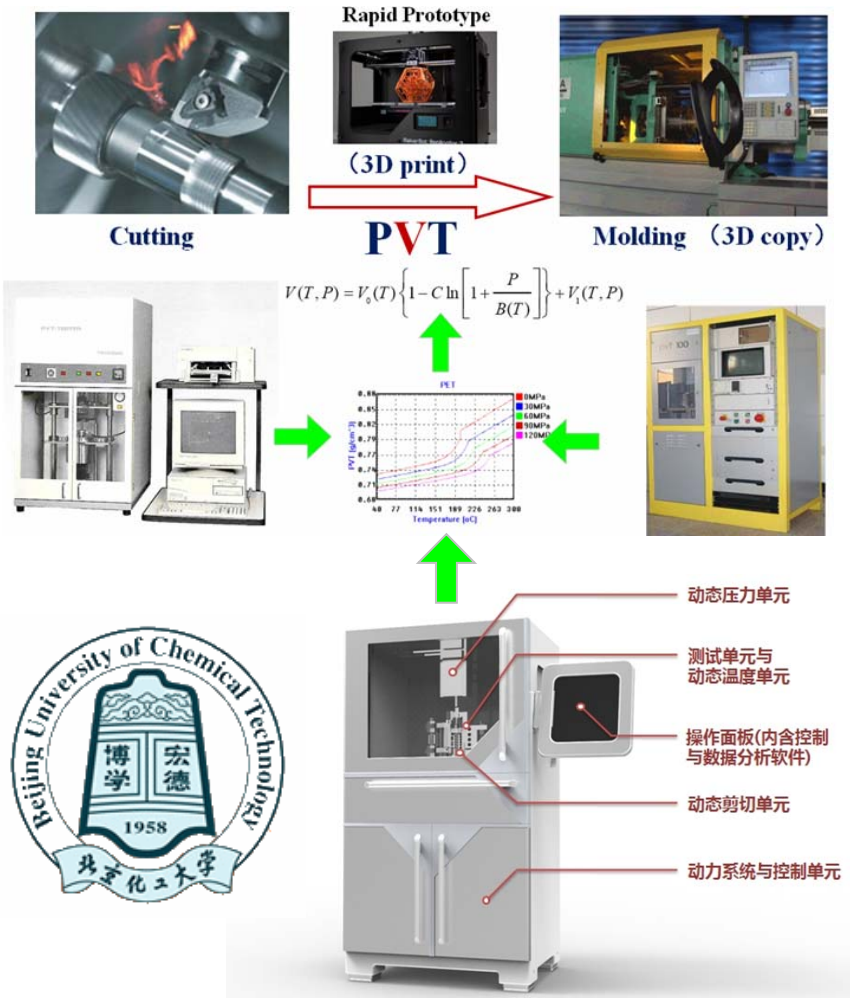
**Develop PVT tester for Ultra-high speed and precision polymer molding and 3D printing**




**Mechanical + Chemical: Solve important scientific and technical problems**

# 3. Future work

**Develop PVT tester for Ultra-high speed and precision polymer molding and 3D printing**



# Acknowledgement

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# Thank you very much