Latest technology innovation for counter rotating continuous mixer

Yoshinori Kuroda
KOBE STEEL, LTD

February 28, 2017

1. Recent material development of Bi-modal HDPE

- For film grade, Bi-modal HDPE has been polymerized with broader molecular weight distribution to improve blown film extrusion processability and toughness.

- For pipe grade, 1-Hexene (C6) instead of 1-Butene (C4) has been applied as a co-monomer component to enhance the strength of the final pipe product.

- However both modifications have brought about more difficulty from a homogenization point of view, so-called a gel issue.

- KOBE has developed the new generation continuous mixer MIXTRON™ "LCM-IM" to respond above mixing performance demand.

2. Development steps

1. Two-dimensional test mixer (batch mixer) trials

   Basic mixing experiments were done to obtain optimized rotor shape dimension by a two-dimensional test mixer.

2. Continuous lab test mixer trials

   Above obtained operation and mixing performance data from two-dimensional mixer have been applied to the development of a continuous mixer, as such from '2-D' information to '3-D' practice.

3. Details of two-dimensional test mixer experiments -1-

The two-dimensional test mixer is composed of,

i) Mixer barrel

ii) Twin rotor counter rotating elements with the various dimensions, which are changed by varying the element sets

iii) Main motor, which is connected through gear reducer to the twin rotor mixing elements

iv) Motor speed can be controlled variably and the torque and the power can be measured during the experimental operation.

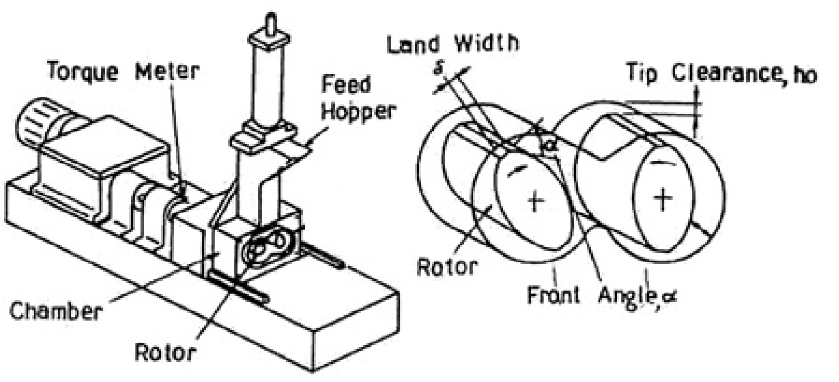

Fig.1 Two – dimensional test mixer

3. Details of two-dimensional test mixer experiments -2-

The effects of rotor dimensions for Bi-modal HDPE mixing homogeneity performance were investigated. Rotor element dimensions, which were a) Tip clearance and b) Rotor front angle, were varied.

Additionally the new concept rotor, [intermeshing] shape was introduced to the experiments.

Table 1 Various rotor element dimensions matrix

<table>
<tr><td colspan="2" rowspan="3"></td><td colspan="3">Conventional shape
[Tangential]</td><td rowspan="3">New Concept Shape
[Intermeshing]</td></tr>
<tr><td colspan="3">Front angle</td></tr>
<tr><td>Small</td><td>STD</td><td>Large</td></tr>
<tr><td rowspan="3">Tip clearance</td><td>Narrow</td><td>Rotor # 15A</td><td>Rotor # 15B</td><td>Rotor # 15C</td><td>Rotor # 15P</td></tr>
<tr><td>STD</td><td>Rotor # 15E</td><td>Rotor # 15F [STD]</td><td>Rotor # 15G</td><td>Rotor # 15Q</td></tr>
<tr><td>Wide</td><td>Rotor # 15H</td><td>Rotor # 15J</td><td>Rotor # 15K</td><td>Rotor # 15R</td></tr>
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3. Details of two-dimensional test mixer experiments -3-

Mixing material compound recipe;

Bi-modal HDPE powder / 2.25 wt% of CB / anti-oxidant

Homogeneity performance evaluation;

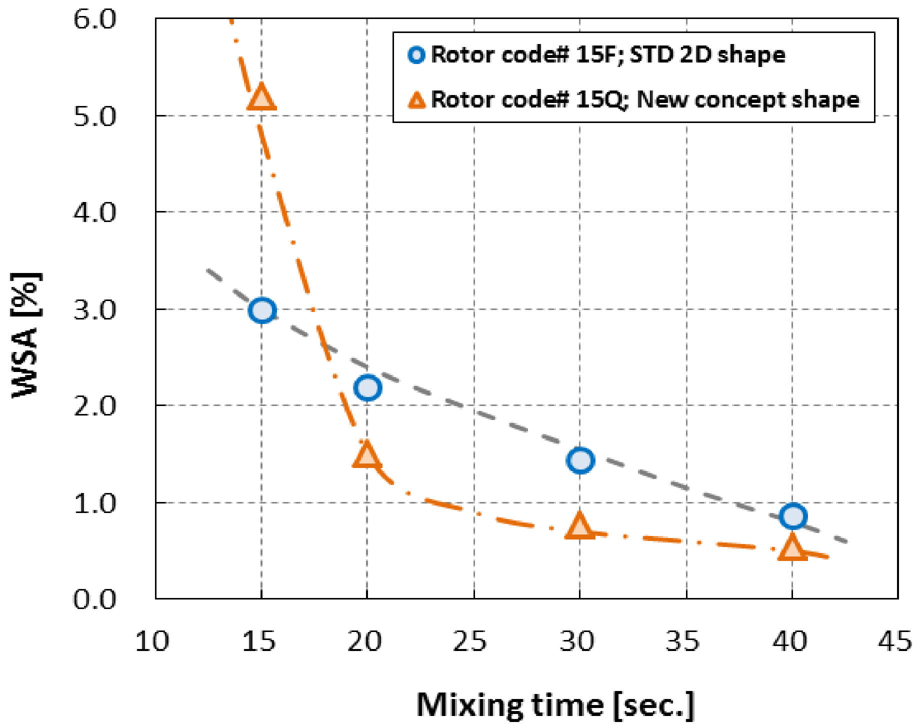
Homogeneity performances were valuated by WSA (White Spot Area; [%]) measurement, which were observed and calculated from a total white spot area versus well mixed black background area in the microscope views. 20 micron m thickness samples were sliced by the rotary microtome, and were observed/measured.

Total WS area [mm^2]	0.0024
Whole area [mm^2]	1.6764
WSA [%]	0.14
WS-ISO Rating [-]	2.5

(x 200 magnification view)

Fig.2 Typical microscopic view of mixed by 2-D test mixer

4. 2-D test mixer experiment results -1-



Rotor Speed; 440 rpm
Fill factor; 70%
(estimated melt density; 0.75 g/cm^3)
Chamber; 160°C Hot Oil Heating

Fig. 3 WSA reduction by mixing time

- Rotor code "#15F" was the best shape among 'tangential' shape
- Rotor code "#15Q" was the best shape among 'intermeshing' shape

4. 2-D test mixer experiment results -2-

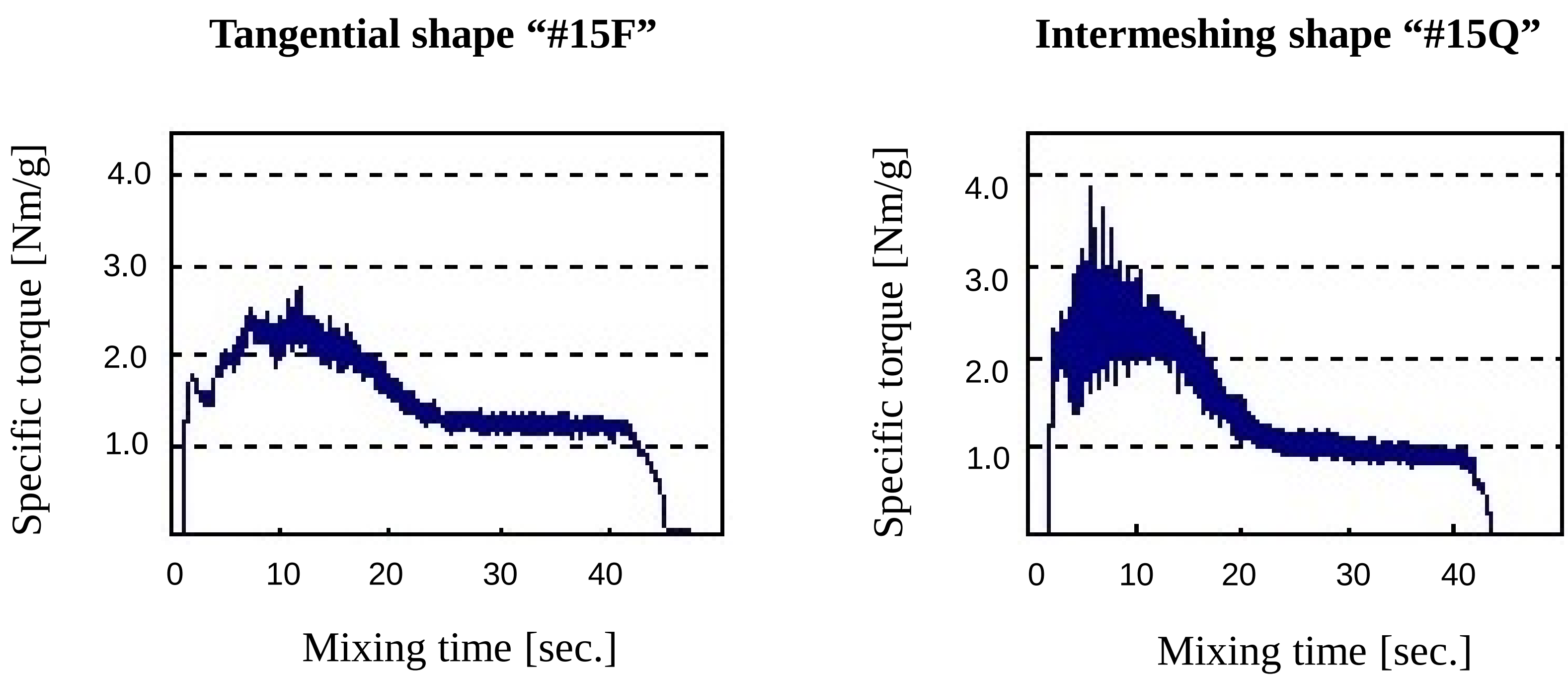


Fig. 4 Specific torque trend by mixing time

- #15Q of intermeshing shape showed 1.5 times peak torque at melting stage (vs #15F), however after melting, specific torque was lower.

5. 2-D test mixer experiment result – summaries -

Table 2 Respective rotor features for melting and mixing performance

	Melting performance	Mixing performance
Tangential "#15F" profile	+ +	+
Intermeshing "#15Q" profile	+	+ +

+ + superior performance
+ standard performance

- Tangential "#15F" brought about 1) shorter melting time, 2) smaller energy consumption, 3) better homogeneity performance at melting stage.
- Intermeshing "#15Q" resulted in 4) smaller energy consumption and 5) better homogeneity performance after melting stage.

6. Basic concept of the new generation continuous mixer

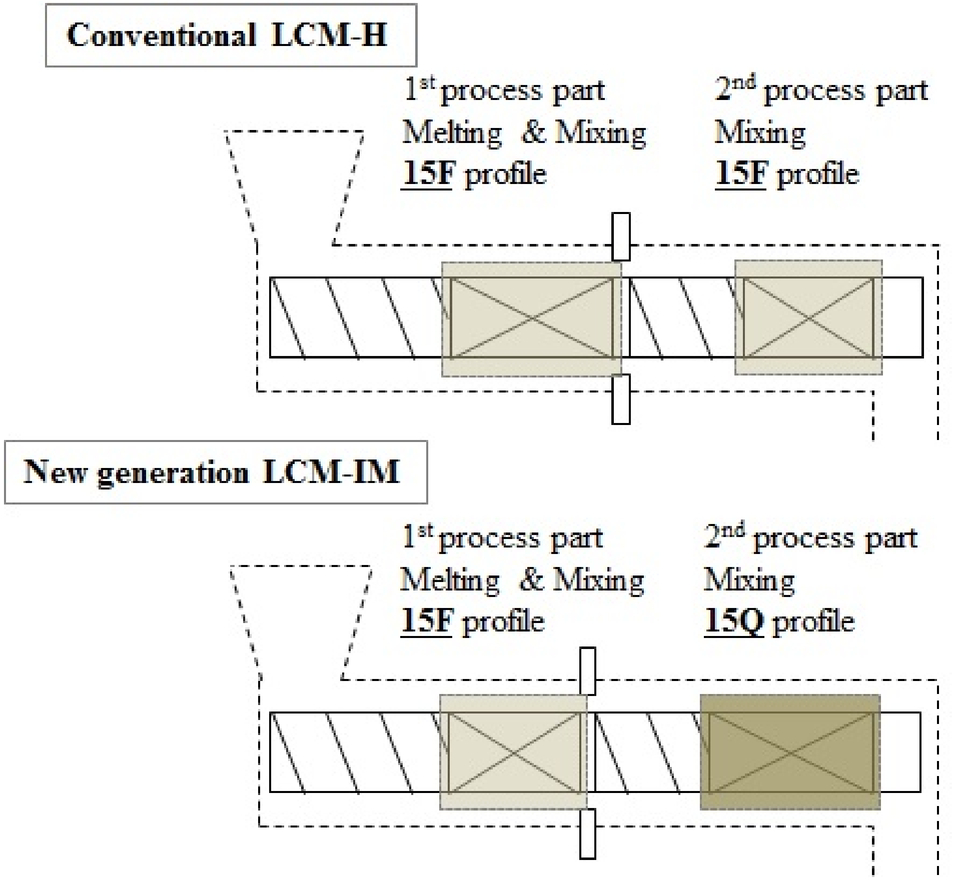
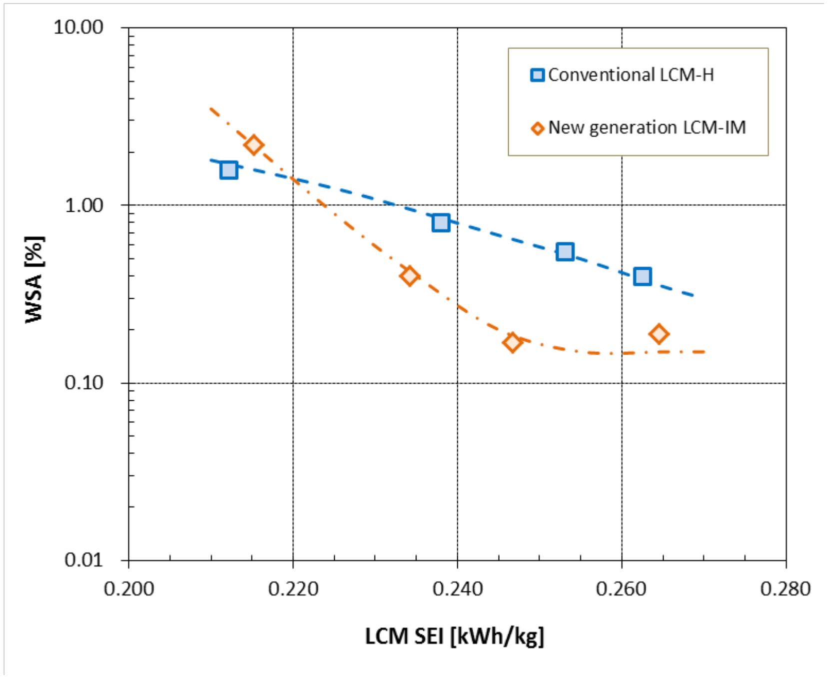


Fig. 5 Comparison between conventional LCM-H and new generation LCM-IM

7. New generation continuous mixer LCM-IM mixing performance improvement 1 – with CB compound



LCM100-H &
LCM100-IM comparison

Pipe grade; $MI_5 = 0.30$
CB; 2.25%

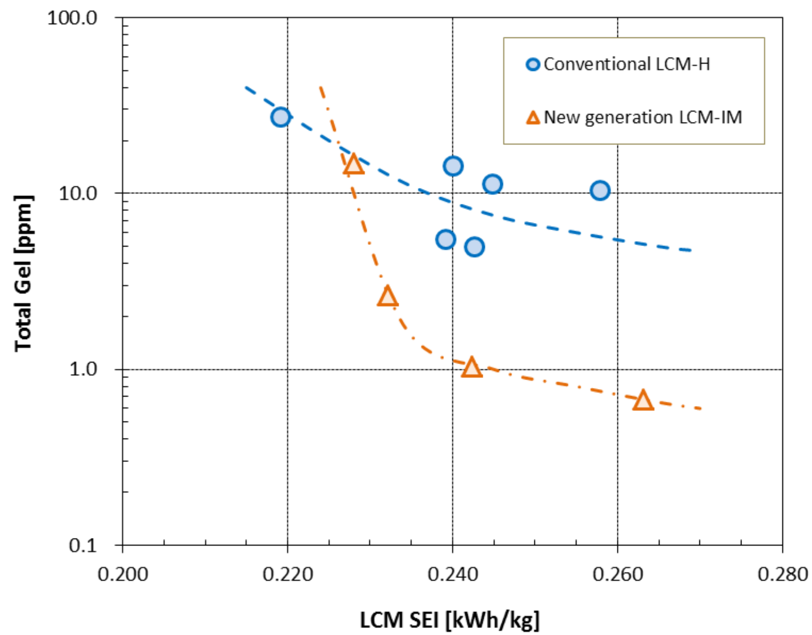
Feed rate; 520 kg/h
(= 45 t/h in LCM450)
(= 60 t/h in LCM500)

Rotor Speed; 440 rpm

Fig. 6 WSA reduction performance comparison by mixer SEI

- A significant improvement of LCM-IM was not observed below 0.220 kWh/kg of SEI, however, higher than 0.220 kWh/kg regions, WSA reduction performance was remarkable. The result from both continuous mixers agreed well with the result from two-dimensional test behaviors.

7. New generation continuous mixer LCM-IM mixing performance improvement 2 – Natural homogeneity



LCM100-H & LCM100-IM comparison

Pipe grade; $MI_5 = 0.25$ (without CB)

Feed rate; 520 kg/h
(= 45 t/h in LCM450)
(= 60 t/h in LCM500)
Rotor Speed; 440 rpm

Evaluated by OCS™ Gel counter

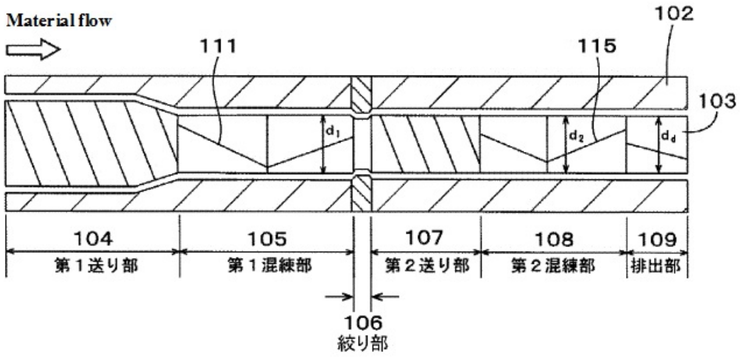
Fig. 7 Gel reduction performance comparison in casting film appearance by mixer SEI

- A significant improvement of LCM-IM was not observed below 0.230 kWh/kg of SEI, however, above 0.230 kWh/kg regions, gel reduction performance was dramatic. The result from both continuous mixers agreed well with the result from two-dimensional test behaviors same as CB compounding results.

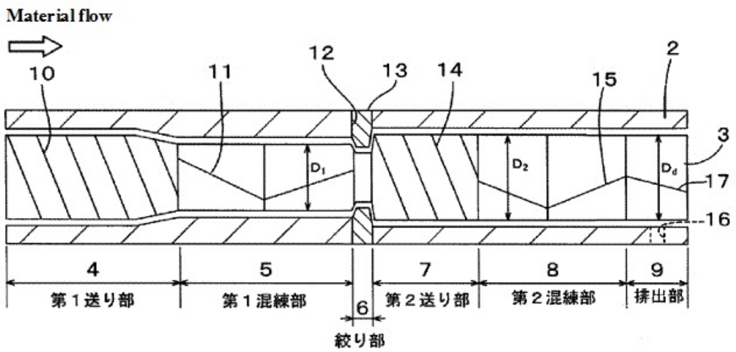
8. Practical LCM-IM design -1-

Rotor arrangement over view comparison
(Both total L/D = 8.0)

Conventional LCM-H design



New generation LCM-IM design



(From PAT; WO 2015 122105 (patent pending))

9. Conclusions

- Improvement of LCM-IM homogeneity performance has been confirmed through lab trials.

- The significant development concepts of LCM-IM are not only superior mixing performance but also “easy retro fitting” to existing LCM-H lines. L/D of both the LCM-H and the LCM-IM is 8.0.

- Moreover a) adjusted raw material feed point, b) mixer support foot-print, and c) the same rotor center-distance mean that a replacement of the LCM may be implemented easily. Users of the LCM-H are able to re-use their existing ‘main motor, melt pump system, screen changer and under water pelletizer system’. Such easy retro fitting policy promises minimized replacement down time of the production line.