Biosciences, Biotechnology Research Asia Vol. **7**(1), 259-266 (2010)

Heat transfer strategies in itaconic acid production by using *Aspergillus terreus* MTCC 479

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(Received: December 16, 2009; Accepted: January 15, 2010)

ABSTRACT

Itaconic acid was best produced by fungal species than bacterial species. The A*spergillus terreus* were known to be the best species for itaconic acid production among the different fungal species studied. However, there was no comprehensive study on using latest technologies for increasing the productivity at industrial level and it was not properly established. For increasing the productivity, the influence of starting substrate concentration, the optimum timing of additional substrate and the possibility of semi-continuous fermentation were analyzed in a bench-top fermentation. In the present study we can analyse the requirements as follows:
The total heat requirement for 3lt bench top fermentor - 103.16 kcal/ hr.
Design of sparger – 10holes with 3mm diameter having 5mm pitch and
Diameter of the shaft required – 13mm for the maximum yield of itaconic acid of 27 g/lt under optimized conditions by *A.terreus.*

Key words: Heat requirement, Itaconic acid, Shaft, Sparger.

INTRODUCTION

Organic acids with wide applications in various fields are made from living cells commercially. Organic acids like citric acid, gluconic acid, itaconic acid and lactic acids are manufactured by means of such large-scale bioprocesses. Among them, the itaconic acid (Methelene Butanedioic acid common synonyms: Methylene succinic acid, 3-carboxy-3-butanoic acid, propylenedicarboxylic acid) is the most promising one.

Itaconic acid is a colorless crystalline carboxylic acid obtained by the fermentation of carbohydrates. Itaconic acid was discovered by Baup (1837) as a thermal decomposition product of citric acid. The biosynthesis by fungi from carbohydrates was first reported by Kinoshita (1932), who isolated itaconic acid from the growth medium of an osmophilic fungus, *Aspergillus itaconicus*. Later, other fungal strains, mainly of the species *Aspergillus terreus*, were found to be more suitable. At the Northern Regional Research Laboratory (NRRL) of the U.S. Department of Agriculture in Peoria, Illinois, a screening programme of more than 300 strains identified the most published strain, *A. terreus* NRRL 1960 (Lockwood and Reeves, 1945). Attempts were also made to develop a biotechnical process for itaconic acid production (Nelson *et al.,* 1952; Pfeifer *et al.,* 1952). Later, optimized industrial processes were established providing the limited market with itaconic acid. The prominent developments in itaconic acid production (batch fermentation, free suspended biomass) took place before 1966 (Petuchow *et al.,* 1980). Over the next 15 years, the interest in itaconic acid production declined, as indicated by the few publications during this time. Since the early 1980s, there has been increasing concern regarding sustainability, environmental conservation, renewable resources and rising energy costs.

Heat transfer design of fermenter

Heat input

i > By air

volume of air at NTP = 0.002 x 60

= 0.12 m^3 /hr

Weight of air = 0.12 x $\frac{29}{22.4}$ = 0.155 kg/hr

Air inlet temp = 70°C

Air outled temp = 25°C

Sp. heat of air at mean temperature = 0.238 $\frac{cal}{g-^{o}C}$

Heat lost by air = in C_p ∇ T

= 0.155 x 0.238 x 2.203 x 45

=3.665 lb-cal / hr

Heat of fermentation = 3.5

= 3.5 x 0.002

=0.007 kw

Heat input due to agitation = 7.5% (power input by impeller)

= 0.075 × 0.1864

= 0.01398 kw

Total = (i) + (ii) + (iii)

= 3.665 + (0.007 + 0.01398) (3414 x $\frac{1}{1.8}$)

= 43.457 lb-cal/hr

Heat output

By evaporation of water

P_o = Vap pressure of water at 25°C = 24 mm Hg

P = Air pressure = 1010 mm Hg

Humidity of saturated air = $\frac{p_o}{p-p_o} x \frac{Mwater}{Mair}$

= $\frac{24}{1010-24} x \frac{18}{29}$

= 0.01511

Quantity of dry air = 0.155 Kg/hr

∴ Quantity of water evaporated = 0.155×0.015 11

=2.342 x 10^{-3} Kg/hr

= 5.159 x 10^{-3} lb/hr

Latent heat of water at 25°C = 583 Cal

Quantity of water = 5.159 x 10^{-3} × 583

= 3.0077 lb cal / hr

= 1.365 Kcal/hr

Heat removed by cooling water = 43.452 – 3.0077

= 40.4443 lb-cal/hr

Cooling water temperature = 18°C

If cooling water exit temperature = 22°C

Quantity of cooling water required =

$\frac{4.5x10^{-5}x144}{3}$ $\frac{10.111}{3600x0.997x62.4}$ = 10.111 lb/hr

Sp Gravity of water at 20°C = 0.997

Volume of water required =

= 4.5 × 10^{-5} ft^3/sec

If water velocity = 3ft/sec

Area of crops section required for flow

=

= 0.002166 in^2

= 2.166 x 10^{-3} in^2

Area of flow of a $\frac{1}{8}$ " inch (sch ; No:40) pipe

= $(0.269)^2$

= 56.8 x 10^3 in^2

pipe of " N.B will serve the purpose

Heat transfer coeffect

O. d = 0.405"

I . d = 0.269"

Out side surface = π do

= π (0.405)

= 1.272 in

L M T D =

=4.7°C

Calculation of coil inside film coeffct

$h_i = \frac{k}{d}$

d = $\frac{0.269}{12}$ ft

d_c = dia of coil = 75 mm = 2.95"

= 1119.69 lb-cal /hr ft² – °C

Calculation of coil outside film coeffct

$$\frac{h_o D_j}{k} = a\left[\frac{L^2.N.S}{\mu}\right]^{0.66}\left[\frac{C_p}{\mu}\right]^{0.66}\left[\frac{C_p.\mu}{k}\right]^{0.33} x\left[\frac{\mu_B}{\mu_s}\right]^{0.14}$$

D_j = Vessel diameter

= 120 mm ft

h_o = 77.73 lb cal/hr. ft² - °C

$$\frac{1}{77.3}+\frac{0.19}{12.96}\left[\frac{0.405}{0.324}\right]+\frac{0.405}{1119.69x0.269}+0...3+\frac{0.001x0.405}{0.269}$$

= 0.015945

U_o = 62.72 $\frac{lb-cal}{hr-ft^2-^oC}$

This value lies between 50 – 150

So, this pipe serve the purpose

Q = U A ∆ T

40.449 = 62.72 A (4.7)

⇒ A = 0.1372 ft²

Surface area of tubes = π d_o

=

= 0.1060ft

Length of pipe required =

= 1.29 ft = 393.192 mm

Length of one tube = 235.6 mm

$$\ldots\left[\frac{\ldots 62.4x3x0.269}{12x2.4}\right]^{0.8}\left[\frac{1x24}{0.35}\right]^{0.4}$$

$\ln\left(\frac{\ldots}{25-22}\right)$ = 1.668

2

Two sets of coils with 2 turns each is used coil diameter = 75 mm, pitch = 5mm

Chemical Engineering design of fermenter

Pressure drop across coils

u = 3 ft /sec

= 3 x 3600 ft/hr

d= 0.269 d_c = 75 mm =2.95"

NR_e = =

= 6242.57

∴ NR_e critical = 20000

= 20000

= 9294.107

NR_e crit > NR_e

NR_e = 9294.107

=77.28

f_c = = 0.0073 + 0.076

=0.0 = 329

f_c = 0.00993

F =

=

= 0.3195 ft

Δ = F x s

=0.3129 x

= 0.138 lb/in^2 (satisfactory)

Heat balance over fermenter daten temp (0°C)

I> Heat input

1. Air

In = 0.155 kg/hr

T_{-1} = 0°C

T_2 = 70°C

C_p = 0.238 cal/g -°C

Q_{air} = in cp ΔT
= 0.155 x 0.238 x 70
= 2.5823 Kcal/hr

2.Fermentation & Agitation = 0.007 + 0.01398

= 0.02098 kw

= 0.02098 K J/sec

$\frac{0.00993 x 1.29 x 12}{0.269} x \frac{9}{2 x 32.2}$ =17.98

3) Cooling water

In = 4.589 kg/hr

C_p = cal/g - °C

T_2 = 18°C

T_1 = 0°C

Q = in CP ΔT

= 4.589 x 1 x 18

Heat balance

	I/P Heat (Kcal/hr)	O/P Heat (Kcal/hr)	
1. Air	2.5823	Air	0.922
2. Fermentation + Agitation	17.98	EΔling water	10.96
Total = 103. 1643		Total = 103.25	

This completes heat transfer design of fermenter

= 82.602 Kcal/hr

Heat Output

Air

in = 0.155 Kg/hr

C_p = 0.238 cal/g-^{o}C

T_2 = 25^{o}C

T_1 = 0^{o}C

Table 1: Itaconic acid production using 100ml & 2 Lt batch reactor by *A. terreus*

S.	Time	Itaconic acid Concentration (g/lt)	
No.	(hrs)	100ml	2 Lt
1	0	0.00	0.00
2	24	1.04	1.03
3	48	5.13	4.93
4	72	8.97	8.05
5	96	13.14	13.09
6	120	27.00	26.40

ANOVA: Two-Factor With out Replication

Q_{air} = in CP T

= 0.155 × 0.238 (25-0)

= 0.92225 Kcal/hr

Evaporation = 1.365 Kcal/hr

Cooling water

in = 4.589 kg/hr

T_2 = 22^{o}C

Q = 4.589 x 1 x 22

= 100.958 Kcal/hr

Design of shaft

Power = 187 w 0.186 kw

n = 200rpm

$$P = \frac{2\pi nT}{60}$$

$$T = \frac{60P}{2\pi N}$$

Summary	Count	Sum	Average	Variance
Row 1	2	0	0	0
Row 2	2	2.07	1.035	5E-05
Row 3	2	10.06	5.03	0.02
Row 4	2	17.02	8.51	0.4232
Row 5	2	26.23	13.115	0.00125
Row 6	2	53.4	26.7	0.18
Column 1	6	55.28	9.213333333	100.0411867
Column 2	6	53.5	8.916666667	96.28694667

ANOVA:

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	981.2802	5	196.25604	2722.249	1.403E-08	5.05032
Columns	0.2640333	1	0.264033333	3.662382	0.1138396	6.60789
Error	0.3604667	5	0.072093333			
Total	981.9047	11				

$= \frac{60x187}{2\pi(200)}$ 8.93 = 9 N – m

T = $\frac{\pi}{16}$ d^3 allowable shear stress for shaft obtained

= 70 MP$_a$

9 x 1000 = x d^3 (70)

d^3 =

d = 12.7 mm

$\cong$ 13 mm

Mechanical design

Design of sparger

Height of liquid = 216 mm = 0.7 ft

Pressure due to liquid heat =

= 0.32 lb/in^2

pressure in vessel = 5 lbf/in^2

$\therefore$ Total pressure at the bottom of vessel = 5+0.32

= 5.32 lb/in^2

Air pressure P$_1$ = 14.7 x 2 = 29.4 lb/in^2 (Abs)

Pressure at bottom P$_2$ = 5.32 + 14.7 = 20.02 lb/in^2 (Abs)

The velocity of flow

$$v\left[1-\left(\frac{p_2}{p_1}\right)\frac{v-1}{v}\right]$$

v = 1.4

u$_1$ = 0

v = $\frac{1}{s}$ = 13.01 $\frac{ft^3}{lb}$

s = 1.29 Kg/m^3 = 0.076 lb/ft^3

$$4_2^2 = \frac{142x29.4x1.4}{1.4-1}x0.00164\left[1-\left(\frac{20.02}{29.4}\right)^{0.2857}\right]$$

4$_2$ = 5.053 ft/sec

Area required for this flow

$$A_2 = \frac{in}{s4_2}$$

$= \frac{0.155x2.203}{0.076x5.053x3600}$

=0.246 x 10^{-3} ft^2

=0.0228 x 10^{-3} m^2

= 22.8 mm^2

[illegible] considering losses

A$_2$ = 44.46 mm^2

Area of 3 mm hole =

= 7.068 mm^2

Number of holes =

= 6.2903

$\cong$ 6 holes

10 holes with 3 mm dia having 5 mm pitch

Welding joints

Shaft diameter = 13 mm

Number of bolts = 4

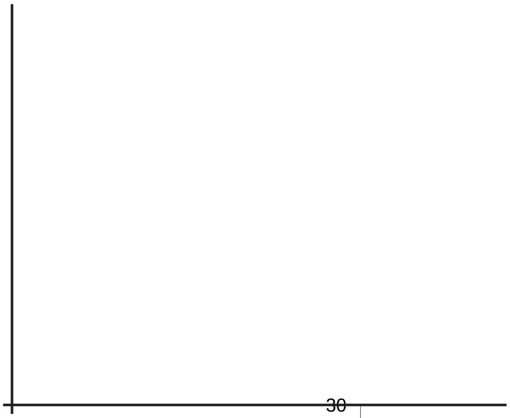
Cover plate thickness = 4 mm

RESULTS AND DISCUSSION

The total heat requirement for 3lt bench top fermentor - 103.16 kcal/ hr. Design of sparger – 10holes with 3mm diameter having 5mm pitch. Diameter of the shaft required – 13mm

Production of Itaconic acid in Batch Fermentation (bench top fermentor)

An investigation has been done to study the maximum production of itaconic acid using different configuration reactors with a configuration volume of 100 ml and 2 batch reactors. *Aspergillus* terreus species were found to give a maximum yield of itaconic acid in 100 ml batch reactor than 2 reactor indicating that the 100 ml reactor was most suited for the production of itaconic acid. *A. terreus* has produced maximum itaconic acid of 27 g/lt (Figure) under optimized conditions (Table). The present observed results were found to be in consonance with the reports of Prucssc *et al.,* (1998).



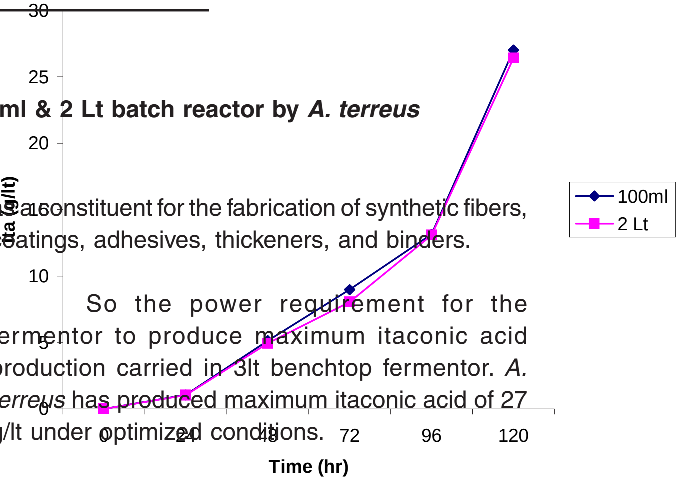


Fig. 1: Itaconic acid production using 100ml & 2 Lt batch reactor by *A. terreus*

CONCLUSION

Recent advancements in the field of industrial biotechnology have led to the development of successful organic acids, which is being used in the production of biodegradable plastics. Itaconic acid is made use as a co-monomer at a level of 1–5% for certain polymer products. It is also important as a constituent for the fabrication of synthetic fibers, coatings, adhesives, thickeners, and binders.

So the power requirement for the fermentor to produce maximum itaconic acid production carried in 3lt benchtop fermentor. *A. terreus* has produced maximum itaconic acid of 27 g/lt under optimized conditions.

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