control of perfusion or HIPCOP" are used to describe the process by which cells control their own rate of perfusion. Volumetric productivities of equal to about, or greater than, 1 gram/L/day for moderate specific productivity cell lines are achieved with very modest medium volumes, comparatively simple bioreactor operations, and a batch length that fits in a standard fed-batch window. The volumetric productivity achieved is more than double what one might achieve with the same cell line in an optimized fed-batch culture.

The subject technology relates to a continuous perfusion culture process comprising monitoring pH in a cell culture in perfusion bioreactor with a pH controller or sensor, activating a medium perfusion pump delivering fresh medium and a permeate perfusion pump removing a nearly equivalent volume of permeate when the pH increases above a setpoint or predetermined value, and deactivating the medium perfusion pump and permeate perfusion pump when the pH decreases below a setpoint or predetermined value. The subject technology relates to a continuous perfusion culture process, including: (a) monitoring pH in a cell culture with a pH sensor; (b) delivering fresh medium and removing permeate when the pH is above a predetermined value; and (c) deactivating the medium delivery and the permeate removal when the pH decreases below the predetermined value. In one aspect, the subject technology relates to a continuous perfusion culture process, comprising: monitoring pH in a cell culture with a pH sensor; delivering fresh medium and removing permeate when the pH is above a predetermined value; and deactivating the medium delivery and the permeate removal when the pH is below the predetermined value, wherein the cell culture is a mammalian cell culture; wherein the fresh medium comprises L-lactate; and wherein the L-lactate is present in the fresh medium in an amount of about 0.1 g/L to 7.0 g/L. In essence, the pH change in the cell culture medium is a result of the cell metabolism which then triggers the perfusion process. Alternatively, the method may be described as a cell-controlled perfusion process without a need to measure glucose concentration. The pH trigger for turning on and off the perfusion pumps, fresh medium and permeate pumps, is set at a predetermined value. This predetermined value is about pH 7 (e.g., between 6.8-7.4). The medium comprises glucose, L-lactate and a specified ratio of amino acid to glucose. According to this subject technology, the activation and deactivation of the medium perfusion pump and the permeate perfusion pump may occur simultaneously or independently. Also, the permeate may be cell-free or may contain cells.

The described method also comprises adding L-lactate to a fresh perfusion medium used in the continuous culture process. In an example, the L-lactate present in the perfusion medium is in an amount of about 0.1 g/L to about 7.0 g/L. More preferably, the L-lactate present in the perfusion medium is in an amount of about 1 to about 4 g/L, about 1 to about 3 g/L, or

about 1 to about 2.5 g/L. In a preferred example, the L-lactate is sodium L-lactate or potassium L-lactate.

In another example, instead of having L-lactate in the perfusion medium, additional sodium bicarbonate is delivered to the fresh medium or to perfusion bioreactor when the pH of the perfusion culture goes above the predetermined value (i.e., pH 7 or a pH of 6.8-7.4). A typical cell culture medium contains about 1.0 to 2.5 g/L of sodium bicarbonate. In this example, however, an additional 1 to 3 grams of sodium bicarbonate is added to the perfusion medium for every 1 liter of perfusion media added to the perfusion cell culture bioreactor when the pH of the cell culture is above pH 6.8 or above pH 7 or above pH 7.4 or above any pH within the range of 6.8 to 7.4. Once the pH drops below the predetermined value, the delivery of sodium bicarbonate is stopped or discontinued. Any other physiologically acceptable base (e.g., sodium carbonate, potassium carbonate, HEPES buffer, or the like), which is known to one of ordinary skill in the art, may be used in place of sodium bicarbonate so long as such base is added to the perfusion bioreactor slowly and at a rate that would provide an upward influence on the pH in a manner similar to that which would occur by the consumption of lactate from the perfusion medium as lactic acid. For example, instead of sodium bicarbonate being added to the perfusion medium, sodium carbonate can be added to the perfusion bioreactor slowly when the pH is above the predetermined value. In an example, the sodium carbonate is added to the perfusion bioreactor such that 1 molar carbonate enters the perfusion bioreactor at a rate of 8.7 mL per 1 liter of perfusion medium utilized.

The fresh medium in this method requires at least glucose and amino acids. In an example, the concentration of glucose is in the range of about 0.5 to about 40 g/L. In another example, the fresh medium contains L-lactate. The concentration of L-lactate is in the range of about 0.1 and about 7.0 g/L. The ratio of moles of glucose to amino acids is between about 0.25 and 1.0. In another example, the fresh medium further contains sodium bicarbonate, in addition to or in place of L-lactate, in an amount of about 2 to 5.5 g/L. In another example, the fresh perfusion medium contains both L-lactate (in an amount of about 0.1 to 7 g/L) and sodium bicarbonate (in an amount of about 2 to about 5.5 g/L) such that the cells will be able to control their perfusion rate over the entire continuous perfusion period according to the subject technology.

Thus, the subject technology also relates to a perfusion culture process, including: (a) monitoring pH in a cell culture in a perfusion bioreactor with a pH sensor; (b) delivering fresh medium and removing permeate when the pH is above a predetermined value; and (c) deactivating the medium delivery and the permeate removal when the pH is below the predetermined value. In one or more examples related, directly or indirectly, to the above to each other, the fresh medium includes L-lactate; the L-lactate is present in the fresh medium in an amount of about 0.1 g/L to 7.0 g/L; the L-lactate is present in the fresh medium in an amount of about 1 to 4 g/L; the L-lactate is present in the fresh medium in an amount of about 1 to 3 g/L; the L-lactate is present in the fresh medium in an amount of about 1 to 2.5 g/L; alternatively or in addition to L-lactate, additional sodium bicarbonate is added to the perfusion medium or the perfusion bioreactor in an amount of about 1 to about 2.5 g/L such that the total sodium bicarbonate in the culture medium is about 2 to about 5.5 g/L and wherein the additional sodium bicarbonate is delivered to the perfusion bioreactor when the pH is above the predetermined value; the additional sodium bicarbonate is added to the perfusion bioreactor such that 1 molar carbonate enters the perfusion bioreactor at a rate of 8.7 mL per 1 liter of perfusion medium utilized; alternatively or in addition to L-lactate, any other physiologically acceptable base such as sodium carbonate, potassium carbonate, or the like is added to the perfusion bioreactor in an amount that would provide an upward influence on the pH in a manner similar to that which would occur by the addition of L-lactate; the fresh medium includes: (a) glucose; (b) L-lactate and/or additional sodium bicarbonate; and (c) amino acids; the fresh medium includes: (a) between about 0.5 to about 40 g/L glucose; (b) between about 0.1 to about 7 g/L L-lactate and/or between about 2 to about 5.5 g/L sodium bicarbonate; and (c) amino acids in a mole-of-glucose-to-mole-of-amino-acids ratio of between about 0.25 to about 1.0 ; the fresh medium includes glucose in an amount equal to about 70 mM of amino acids and about 5.3 grams of glucose per liter of medium; the fresh medium includes glucose at an amino-acids-(in mM)-to-glucose-(in g/L) ratio selected from the group consisting of about 60 to about 4.2; about 90 to about 8; about 100 to about 12; about 120 to about 13; about 240 to about 42 and about 380 to about 70 per liter of medium; the predetermined pH value is about pH 7 or is about 6.8 to about 7.4; a measurement of glucose concentration in the cell culture or addition of glucose to the cell culture by a glucose pump is not required.

The subject technology also relates to a method for achieving rapid cell growth in a perfusion culture process, comprising: (a) monitoring pH in a cell culture in a perfusion bioreactor with a pH sensor; (b) delivering fresh medium and removing permeate when the pH is above a predetermined value; and (c) deactivating the medium delivery and the permeate removal when the pH is below the predetermined value. In another aspect, the subject technology relates to method for achieving rapid cell growth in a continuous perfusion culture process, comprising: monitoring pH in a cell culture with a pH sensor; delivering fresh medium and removing permeate when the pH is above a predetermined value; and (c) deactivating the medium delivery and the permeate removal when the pH is below the predetermined value, wherein the cell culture is a mammalian cell culture; and wherein the fresh medium comprises: (a) between about 0.5 and 40 g/L glucose; (b) between about 0.1 to 7.0 g/L L-lactate; and (c) amino acids in a ratio of between about 0.25 and 1.0 of mole glucose to mole amino acids. In one or more examples related, directly or indirectly, to the above to each other, the fresh medium comprises L-lactate; L-lactate is in an amount of about 0.1 g/L to 7.0 g/L; alternatively or in addition to L-lactate, additional sodium bicarbonate is added to the perfusion bioreactor in an amount of about 1 to about 2.5 g/L such that the total sodium bicarbonate in the culture medium is about 2 to about 5.5 g/L and wherein the additional sodium bicarbonate is delivered to the perfusion bioreactor when the pH is above the predetermined value; the additional sodium bicarbonate is added to the perfusion bioreactor such that 1 molar carbonate enters the perfusion bioreactor at a rate of 8.7 mL per 1 liter of perfusion medium utilized; alternatively or in addition to L-lactate, any other physiologically acceptable base such as sodium carbonate, potassium carbonate, or the like is added to the perfusion bioreactor in an amount that would provide an upward influence on the pH in a manner similar to that which would occur by the addition of L-lactate; the fresh medium includes: (a) glucose; (b) L-lactate and/or additional sodium bicarbonate; and (c) amino acids; the fresh medium includes: (a) between about 0.5 to about 40 g/L glucose; (b) between about 0.1 to about 7 g/L L-lactate and/or between about 2 to about 5.5 g/L sodium bicarbonate; and (c) amino acids in a mole-of-glucose-to-mole-of-amino-acids ratio of between about 0.25 to about 1.0 ; the fresh medium includes glucose in an amount equal to

about 70 mM of amino acids and about 5.3 grams of glucose per liter of medium; the fresh medium includes glucose at an amino-acids-(in mM)-to-glucose-(in g/L) ratio selected from the group consisting of about 60 to about 4.2; about 90 to about 8; about 100 to about 12; about 120 to about 13; about 240 to about 42 and about 380 to about 70 per liter of medium; the predetermined pH value is about pH 7 or is about 6.8 to about 7.4; a measurement of glucose concentration in the cell culture or addition of glucose to the cell culture by a glucose pump is not required; a viable cell density of about 60 x 10^6/mL is achieved within 4 days.

The subject technology also relates to a hybrid perfusion/fed-batch culture process. In another aspect, the subject technology relates to a hybrid culture process, comprising: the continuous perfusion culture process as defined herein as the first culture process. This process comprising using the continuous perfusion process described above in combination with a fed-batch process. According to the subject technology, the process would

run in perfusion mode for 4 to 6 days prior to being switched to fed-batch mode for an additional 4 to 8 days. By using this hybrid mode, volumetric productivity of equal to about or greater than 1.0 gram/L/day is achieved. In this example, the continuous perfusion culture process includes steps (a) monitoring pH in a cell culture with a pH sensor; (b) delivering fresh medium and removing permeate when the pH is above a predetermined value; (c) and deactivating the medium delivery and the permeate removal when the pH is below the predetermined value.

The subject technology also relates to a continuous perfusion bioreactor which consists of two significantly different phases. The first phase includes the initial continuous phase as mentioned above (ramp up of cell density and perfusion rate using HIPCOP) utilizing a comparably dilute medium, followed by a second phase of perfusion in which the perfusion rates are significantly reduced by utilization of a highly concentrated perfusion medium. By using this two-phase perfusion system, volumetric productivities of equal to about or greater than 1.5 grams/L/day is achieved while using very modest volumes of perfusion medium. No significant cell bleed (removal of cells from the bioreactor) occurs in the examples presented in this application.

The subject technology also relates to the use of a diluent liquid that is added to the bioreactor during the later stages of the perfusion culture when the concentrated perfusion medium is being added to the bioreactor. In one example, such a diluent liquid is a solution of saline of appropriate concentration. Because the long-distance transport of liquid nutrient medium can incur many difficulties (cost of transport, maintenance of sterility, temperature control) there is significant value in using highly concentrated perfusion medium in an industrial setting. Such medium allows for perfusion rates as low as 0.05-0.30 reactor volumes per day for the concentrated perfusion medium. In a related example, in such a bioreactor system it is necessary to flush product material out of the bioreactor, particularly if a continuous downstream process is linked directly to capture the continuously delivered upstream harvest material (e.g., the material coming through the hollow fiber cell retention system), and if the protein being produced is highly labile.

The subject technology also relates to a hybrid culture process, including a first continuous perfusion culture process followed by a second continuous perfusion culture process, wherein the first continuous perfusion culture process includes steps (a) monitoring pH

in a cell culture with a pH sensor; (b) delivering fresh medium and removing permeate when the pH is above a predetermined value; (c) and deactivating the medium delivery and the permeate removal when the pH is below the predetermined value.; and wherein the second continuous perfusion culture process includes steps of (a) adding a concentrated medium; and (b) adding a diluent. In a related example, the hybrid culture process optionally includes an intervening fed-batch step. In this example, the first continuous perfusion culture process is carried out first followed by a fed-batch step which is then followed by the second continuous perfusion culture process. In one or more examples related, directly or indirectly, to the above to each other, the continuous perfusion culture process is the first culture process; the continuous perfusion culture process is followed by a fed-batch process; the continuous perfusion culture process is followed by a second continuous perfusion culture process; the second continuous perfusion culture process comprises the steps of: (a) adding a concentrated medium; and (b) adding a diluent; the concentrated medium comprises 600 millimolar amino acids, 90 grams/liter glucose, 0 g/L sodium L-lactate; the diluent is selected from the group consisting of saline and water; the saline or water normalizes osmotic strength of culture medium to between about 0 to 250 and/or 250 to 350 mOsm/kg; the saline comprises 2.0 g/L sodium bicarbonate, 2.4 g/L polyvinyl alcohol, 20 mM potassium chloride, and 80 mM sodium chloride; the hybrid culture process results in volumetric productivity of greater than 1 gram cells/L/day; the hybrid culture process is performed in a culture volume of about 50 and about 150 L; the culture volume is about 70 L.

The subject technology also relates to a bioreactor for conducting a continuous perfusion culture process, wherein the continuous perfusion culture process includes steps of: (a) monitoring pH in a cell culture in a perfusion bioreactor with a pH sensor; (b) delivering fresh medium and removing permeate when the pH is above a predetermined value; (c) and deactivating the medium delivery and the permeate removal when the pH is below the predetermined value. In one or more examples related, directly or indirectly, to

is above the predetermined value; the additional sodium bicarbonate is added to the perfusion bioreactor such that 1 molar carbonate enters the perfusion bioreactor at a rate of 8.7 mL per 1 liter of perfusion medium utilized; alternatively or in addition to L-lactate, any other physiologically acceptable base such as sodium carbonate, potassium carbonate, or the like is added to the perfusion bioreactor in an amount that would provide an upward influence on the pH in a manner similar to that which would occur by the addition of L-lactate; the fresh medium includes: (a) glucose; (b) L-lactate and/or additional sodium bicarbonate; and (c) amino acids; the fresh medium includes: (a) between about 0.5 to about 40 g/L glucose; (b) between about 0.1 to about 7 g/L L-lactate and/or between about 2 to about 5.5 g/L sodium bicarbonate; and (c) amino acids in a mole-of-glucose-to-mole-of-amino-acids ratio of between about 0.25 to about 1.0 ; the fresh medium includes glucose in an amount equal to about 70 mM of amino acids and about 5.3 grams of glucose per liter of medium; the fresh medium includes glucose at an amino-acids-(in mM)-to-glucose-(in g/L) ratio selected from the group consisting of about 60 to about 4.2; about 90 to about 8; about 100 to about 12; about 120 to about 13; about 240 to about 42 and about 380 to about 70 per liter of medium; the predetermined pH value is about pH 7 or is about 6.8 to about 7.4; a measurement of glucose concentration in the cell culture or addition of glucose to the cell culture by a glucose pump is not required.

In another aspect, the subject technology relates to a perfusion culture process, comprising: (a) monitoring pH in a cell culture in a perfusion bioreactor with a pH sensor; (b) delivering fresh medium to the perfusion bioreactor and removing permeate when the pH is above a predetermined value; and (c) deactivating the medium delivery and the permeate removal when the pH is below the predetermined value, wherein the cell culture is a mammalian cell culture; wherein the fresh medium comprises L-lactate; and wherein L-lactate is present in the fresh medium in an amount of about 0.1 g/L to 7.0 g/L.

In another aspect, the subject technology relates to a method for achieving rapid cell growth in a perfusion culture process, comprising: (a) monitoring pH in a cell culture in a perfusion bioreactor with a pH sensor; (b) delivering fresh medium to the perfusion bioreactor and removing permeate when the pH is above a predetermined value; and (c) deactivating the

medium delivery and the permeate removal when the pH is below the predetermined value, wherein the cell culture is a mammalian cell culture; and wherein the fresh medium comprises L-lactate is in an amount of about 0.1 g/L to 7.0 g/L.

The subject technology also relates to a protein of interest produced by a method including: (a) culturing cells comprising a gene that encodes the protein of interest in a perfusion cell culture bioreactor under conditions that allow production of the protein of interest including: (i) monitoring pH in the cell culture in a perfusion bioreactor with a pH sensor; (ii) delivering fresh medium and removing permeate when the pH is above a predetermined value; and (iii) deactivating the medium delivery and the permeate removal when the pH is below the predetermined value, (b) harvesting the protein of interest from the cell culture bioreactor. In one or more examples related, directly or indirectly, to the above to each other, the fresh medium includes: (a) glucose, (b) L-lactate, and (c) amino acids; L-lactate is in an amount of about 0.1 g/L to 7.0 g/L; alternatively or in addition to L-lactate, additional sodium bicarbonate is added to the perfusion bioreactor in an amount of about 1 to about 2.5 g/L such that the total sodium bicarbonate in the culture medium is about 2 to about 5.5 g/L and wherein the additional sodium bicarbonate is delivered to the perfusion bioreactor when the pH is above the predetermined value; the additional sodium bicarbonate is added to the perfusion bioreactor such

CLAIMS

What is claimed is:

1. A continuous perfusion culture process, comprising:

(a) monitoring pH in a cell culture with a pH sensor;
(b) delivering fresh medium and removing permeate when the pH is above a predetermined value; and
(c) deactivating the medium delivery and the permeate removal when the pH is below the predetermined value,

wherein the cell culture is a mammalian cell culture; wherein the fresh medium comprises L-lactate; and wherein the L-lactate is present in the fresh medium in an amount of about 0.1 g/L to 7.0 g/L.

2. The process according to claim 1, wherein the L-lactate is present in the fresh medium in an amount of about 1 to 4 g/L.

3. The process according to claim 2, wherein the L-lactate is present in the fresh medium in an amount of about 1 to 3 g/L.

4. The process according to claim 3, wherein the L-lactate is present in the fresh medium in an amount of about 1 to 2.5 g/L.

5. The process according to claim 1, wherein the L-lactate is sodium L-lactate or potassium L-lactate.

6. The process according to claim 1, wherein the fresh medium further comprises:

(a) glucose;
and
(b) amino acids.

7. The process according to claim 1, wherein the fresh medium comprises:

(a) between about 0.5 and 40 g/L glucose;

(b) between about 0.1 and 7 g/L L-lactate; and

(c) amino acids in a ratio of between about 0.25 and 1.0 mole glucose to mole amino acids.

8. The process according to claim 6, wherein the amino acids and glucose are provided in an amount equal to 70 mM amino acids and 5.3 grams of glucose per liter of medium or at ratios selected from the group consisting of 60:4.2; 90:8; 100:12; 120:13; 240:42 and 380:70 mM amino acids:grams/L glucose per liter of medium.

9. The process according to claim 1, wherein the predetermined value is about pH 7.

10. The process according to claim 1, wherein the measurement of glucose concentration in the cell culture or addition of glucose to the cell culture by a glucose pump is not required.

11. A method for achieving rapid cell growth in a continuous perfusion culture process, comprising:

(a) monitoring pH in a cell culture with a pH sensor;

(b) delivering fresh medium and removing permeate when the pH is above a predetermined value; and

(c) deactivating the medium delivery and the permeate removal when the pH is below the predetermined value,

wherein the cell culture is a mammalian cell culture; and wherein the fresh medium comprises:

(a) between about 0.5 and 40 g/L glucose;

(b) between about 0.1 to 7.0 g/L L-lactate; and

(c) amino acids in a ratio of between about 0.25 and 1.0 of mole glucose to mole amino acids.

12. The method of claim 11, wherein the measurement of glucose concentration in the cell culture or addition of glucose to the cell culture by a glucose pump is not required.

13. A hybrid culture process, comprising: the continuous perfusion culture process of claim 1 as the first culture process.

14. The hybrid culture process of claim 13, wherein the continuous perfusion culture process is followed by a fed-batch process.

15. The hybrid culture process of claim 13, wherein the continuous perfusion culture process is followed by a second continuous perfusion culture process.

16. The hybrid culture process of claim 15, wherein the second continuous perfusion culture process comprises the steps of:

(a) adding a concentrated medium; and

(b) adding a diluent.

17. The hybrid culture process of claim 16, wherein the concentrated medium comprises 600 millimolar amino acids, 90 grams/liter glucose, 0 g/L sodium L-lactate.

18. The hybrid culture process of claim 16, wherein the diluent is selected from the group consisting of saline and water.

19. The hybrid culture process of claim 18, wherein the saline or water normalizes osmotic strength of culture medium to between about 0 to 250 and/or 250 to 350 mOsm/kg.

20. The hybrid culture process of claim 18, wherein the saline comprises 2.0 g/L sodium bicarbonate, 2.4 g/L polyvinyl alcohol, 20 mM potassium chloride, and 80 mM sodium chloride.

21. The hybrid culture process of any of claims 13 to 20, wherein the hybrid culture process results in volumetric productivity of greater than 1 gram cells/L/day.

22. The hybrid culture process of any of claims 13 to 20, wherein the hybrid culture process is performed in a culture volume of about 50 and about 150 L.

23. The hybrid culture process of claim 22, wherein the culture volume is about 70 L.

24. A perfusion culture process, comprising:

(a) monitoring pH in a cell culture in a perfusion bioreactor with a pH sensor;

(b) delivering fresh medium to the perfusion bioreactor and removing permeate when the pH is above a predetermined value; and

(c) deactivating the medium delivery and the permeate removal when the pH is below the predetermined value,

wherein the cell culture is a mammalian cell culture; wherein the fresh medium comprises L-lactate; and wherein L-lactate is present in the fresh medium in an amount of about 0.1 g/L to 7.0 g/L.

25. The perfusion culture process according to claim 24, wherein L-lactate is present in the fresh medium in an amount of about 1 g/L to 4 g/L.

26. The perfusion culture process of according to claim 24, wherein in addition to L-lactate, sodium carbonate is added to the perfusion bioreactor when the pH is above the predetermined value.

27. The perfusion culture process of according to claim 26, wherein the sodium carbonate is added to the perfusion bioreactor such that 1 molar carbonate enters the perfusion bioreactor at a rate of 8.7 mL per 1 liter of perfusion medium utilized.

28. The perfusion culture process of according to claim 24, wherein in addition to L-lactate, a physiologically acceptable base is added to the perfusion bioreactor to provide an upward influence on the pH in a manner similar to that which would occur by the consumption of lactate from the perfusion medium as lactic acid.

29. The perfusion culture process according to claim 24, wherein the L-lactate is sodium L-lactate or potassium L-lactate.

30. The perfusion culture process according to claim 24, wherein the fresh medium further comprises:

(a) glucose;

and

(b) amino acids.

31. The perfusion culture process according to claim 30, wherein the fresh medium comprises:

(a) between about 0.5 to about 40 g/L glucose;
(b) between about 0.1 to about 7 g/L L-lactate; and
(c) amino acids in a mole-of-glucose-to-mole-of-amino-acids ratio of about 0.25 to about 1.0.

32. The perfusion culture process according to claim 24, wherein the fresh medium further comprises about 5.3 grams of glucose per liter of medium and amino acids in an amount equal to about 70 mM, or wherein the fresh medium further comprises glucose at an amino-acids-(in mM)-to-glucose-(in g/L) ratio selected from the group consisting of about 60 to about 4.2; about 90 to about 8; about 100 to about 12; about 120 to about 13; about 240 to about 42 and about 380 to about 70 per liter of medium.

33. The perfusion culture process according to claim 24, wherein the predetermined value is about pH 7.

34. The perfusion culture process according to claim 24, wherein a measurement of glucose concentration in the cell culture or addition of glucose to the cell culture by a glucose pump is not required.

35. A method for achieving rapid cell growth in a perfusion culture process, comprising:

(a) monitoring pH in a cell culture in a perfusion bioreactor with a pH sensor;
(b) delivering fresh medium to the perfusion bioreactor and removing permeate when the pH is above a predetermined value; and
(c) deactivating the medium delivery and the permeate removal when the pH is below the predetermined value,

wherein the cell culture is a mammalian cell culture; and wherein the fresh medium comprises L-lactate is in an amount of about 0.1 g/L to 7.0 g/L.

36. The method of claim 35, wherein the fresh medium comprises:

(a) between about 0.5 to about 40 g/L glucose;

(b) between about 0.1 to about 7.0 g/L L-lactate; and

(c) amino acids in a mole-of-glucose-to-mole-of-amino-acids ratio of about 0.25 to about 1.0.

37. The method of claim 36, wherein in addition to L-lactate, sodium carbonate is added to the perfusion bioreactor when the pH is above the predetermined value.

38. The method of claim 37, wherein the sodium carbonate is added to the perfusion bioreactor such that 1 molar carbonate enters the perfusion bioreactor at a rate of 8.7 mL per 1 liter of perfusion medium utilized.

39. The method of claim 35, wherein a measurement of glucose concentration in the cell culture or addition of glucose to the cell culture by a glucose pump is not required.